675

CENTRAL ELECTRICAL STATIONS.

CENTRAL ELECTRICAL STATIONS:

THEIR

DESIGN, ORGANISATION, AND MANAGEMENT.

BY

CHARLES HENRY WORDINGHAM, A.K.C.,

MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS; MEMBER OF THE INSTITUTION OF MECHANICAL ENGINEERS; EX-MEMBER OF COUNCIL OF THE INSTITUTION OF ELECTRICAL ENGINEERS; PAST PRESIDENT OF THE MUNICIPAL ELECTRICAL ASSOCIATION; MEMBER OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, ETC., ETC.; CITY ELECTRICAL AND TRAMWAYS ENGINEER, MANCHESTER.

LONDON:

CHARLES GRIFFIN AND COMPANY, LIMITED,

EXETER STREET, STRAND.

1901.

PRINTED BY
NEILL AND COMPANY, LIMITED,
EDINBURGH.

PREFACE.

THE literature dealing with Central Station practice is, at the present time, exceedingly limited, but that relating to many of its branches is altogether as extensive and complete, notably that dealing with the steam engine, the dynamo machine, steam boilers, and many other subjects. At least as exhaustive in treatment are the text-books dealing with the abstract sciences underlying these machines and appliances, as thermodynamics, mechanics, electrical theory.

A complete treatise on Central Station work would involve the production of a whole library of many volumes, for no field of engineering practice involves more varied and numerous branches of science, pure and applied, and to attempt to cover adequately in a single book the whole of the ground necessary for the complete exposition of the subject would be a task as futile as it would be absurd to undertake.

Recognising these facts, the Author has attempted in the present work to describe those problems which arise in the practical operation of Central Stations, whether of a scientific, an engineering, or a commercial nature, and to indicate the solution which his own experience, or that of other engineers similarly placed, has dictated. He has endeavoured to avoid more than a reference to those matters which can be found so fully and so ably treated in existing text-books and treatises, and to elaborate and treat fully those subjects which, though perhaps familiar to Central Station engineers, are not, to his knowledge, to be found readily, if at all, in any book. This will explain what might otherwise be considered the want of due proportion in the amount of space devoted to the various items considered with reference to their relative importance. For example, more attention may be given to the details of the jointing

of a main than to the theory of the steam engine, but the student may search in vain elsewhere for the one, while he may satiate himself with treatises on the other.

In these days of voluminous and, it must be said, indiscriminate publication, when the student is so overwhelmed with literature that he is appalled at its mass and knows not what he must read or what he may safely reject, the only justification for swelling the torrent is the writing of a book that will cover some ground that has been left bare by an eddy of the passing stream. It is only a feeling that the subject of this book presents such a case that has induced the Author to devote time taken from the scanty leisure of an exceptionally busy professional life—and it is wholly in such leisure that this book has been written—to add his quota to the publications of the day; and it is his earnest hope that his endeavour to present the latest results of actual practice to his readers may prove of some service to the student, and even to his brother engineers, who are grappling, like himself, with the doubts and difficulties of a new industry, the ultimate development of which no man can yet gauge.

C. H. WORDINGHAM.

MANCHESTER, 1901.

CONTENTS.

LIST OF FORMS.

LIST OF ILLUSTRATIONS.

CENTRAL ELECTRICAL STATIONS.

CHAPTER I.

INTRODUCTORY.

The development of energy in central stations, and its distribution to a number of separate consumers in the vicinity, is a matter which has long attracted the attention of engineers, and the problem has been attacked in many ways with greater or less success.

It can readily be shown, indeed it may almost be taken as an axiom, that, quantity for quantity, it is more economical to produce energy in a form available for the service of man, on a large scale than on a small; the chief difficulty that has been experienced has been in the transmission of the energy from the central station at which it is produced to the points at which it is utilised. On the efficiency of this transmission depends the commercial success of the operation; obviously, the loss in transmission must be less than the saving by concentration of the producing plant if success is to be attained.

As an example of a means of transmission which has been tried and found wanting on an extended scale, may be cited compressed air, while gas, water under pressure, and electrical energy are instances of agents in practical every-day use, each of which has attained a large measure of usefulness in its own sphere.

With electrical energy only as a transmission agent is this book concerned. Its use for the purpose is of recent date, the application being well within the last quarter of a century, and its development has been rapid. Not unhealthily rapid, however; there has been no sudden rush to adopt it merely because of its novelty; on the contrary, its development in this country, at all events, was greatly hampered by legislation, and still more by dishonest commercial operations. For this very reason, it has made sure progress, having had to depend, as all real progress has to depend, on its own merits, and now the production of electrical energy in central stations, and its transmission over extended areas to numerous points of utilisation,

has become firmly established, and, in the near future, it appears probable that an enormous development of this branch of engineering will take place.

Progress has indeed been most rapid already. The first public supply station was established in this country in 1882, and already there are 190 such stations in active operation, with plant having an aggregate capacity of over a quarter of a million horse-power.

Electric lighting is increasing daily in popular favour on account of its manifold and manifest advantages, and as the cost of production diminishes, its use extends at an ever-increasing rate; indeed, if its price be sufficiently reduced, it is likely to be universally used as an illuminant. Its cost must always have remained high had not the concentration of the generating plant in large central stations been carried out.

Important as is lighting, the use of electrical motive power appears likely to eclipse it in importance. Already small users of power are adopting it wherever available; and even large factories, in which the power required is reckoned in hundreds of horse-power, are driven by means of electrical energy derived from central stations. Again, tramcars are rapidly being converted from horse to electric traction, and in America the use of horses for the purpose has nearly ceased. Smelting and chemical manufacturing processes are being operated from central stations, and every day sees new uses being found for energy delivered at a low rate of charge in an electrical form.

The more widely the field is extended, the greater are the opportunities of reducing the cost of the energy; and the establishment of electric central stations is opening up possibilities the full effect of which it is difficult to estimate.

It may be well here to define exactly what are the operations which take place in connection with a central station. In common speech there is necessarily, and very pardonably, much laxity of expression, and to be too precise savours of the pedant. In the course of this book, doubtless, inexact expressions will be used, which, taken literally, imply either impossibilities or absurdities. Thus, to speak of the 'generation' of energy is absurd, for it is as impossible for man to do this as to add one cubit to his stature. What is really done is to alter the form of energy already existing, part being raised in the scale and converted into a form more immediately available for the needs of man, and part, alas irrevocably, so far as we know, degraded. Again, we speak of 'consumers' of energy; obviously that which is indestructible cannot be consumed, and what really happens is the reconversion of the energy into some other special form. Provided that there be no misconception as to the real nature of the operations, and that the intended meaning is well known, this inexactness is of no moment, and the use of common expressions is convenient.

Let it be understood, then, that, in an electrical central station, energy, either in the form of kinetic energy resident in running water, for example,

or of potential energy in the form of chemical affinity, existing, say, in coal, is converted through one or more stages into electrical energy; this energy is transmitted in an electrical form through conductors, part being at once reconverted into potential chemical energy, or frittered away into low temperature heat, and the greater portion reconverted into heat, light, mechanical energy, chemical energy, or some other desired form.

In ordinary language, this process would be described by saying electrical energy is generated by water, steam, or gas power, is transmitted with a certain amount of loss, and the greater portion is consumed as heat, light, chemical action, or in some other way.

Although a certain amount of licence is admissible, too strong a protest cannot be made against the misleading use of terms, such as the confusion of power and energy, heat and temperature, etc.: such lapses show merely ignorance and obscure ideas.

Electrical science lends itself readily to exact statement, and central station work appears to have a special fascination for statisticians. Several most excellent works exist in which entirely reliable accounts are given of the system and plant in use in the various stations of this country, together with full details of their size, character, etc., and the financial results of the operation of the stations. This book is not intended in any way to cover this ground already so well occupied, but rather to discuss the general principles of central station design and operation, the training desirable for an engineer taking up this branch of the profession, and the field that he may reasonably expect to be open to him. It is intended partly for the use of students, but, more especially, for those who have already entered upon practical work, and have charge of stations of their own. It is hoped that the former will find the matter none the less useful to them for its extended scope; indeed, it is hard to draw the line between student and engineer: the true engineer is ever a student, and the lesson he learns more thoroughly as time goes on is a consciousness of how very little he or any of his brother engineers really know.

It is the Author's desire to give a broad account of central station work as it is to-day, and to discuss the best way of meeting present and future demands in connection with it. It will be his endeavour to secure that all statements of fact are entirely accurate, and that the advantages and disadvantages of various systems are presented with absolute impartiality; but, so far as opinions enter into the matter, it is inevitable that some reflection of personal bias should be present, and this, it is hoped, will not be entirely a drawback, for every reader must form his own opinion, and it is better that he should weigh together a number of different and opposing opinions, expressed by different authors, than that he should merely have the facts before him, and draw his own unaided conclusions, which are not more likely to be correct than those of any one of the authors whose works he reads.

CHAPTER II.

CENTRAL STATION WORK AS A PROFESSION.

ELECTRICAL engineering is the most recently developed branch of the work of the civil engineer, and the latest phase of electrical engineering is central station work.

Modern engineering tends more and more to specialisation. There must be first the foundation of general principles, but the student soon learns that he must concentrate his attention on one particular branch, and already the electrical field has become so extended that the operations of any one man must be narrowed down to one particular portion of this if he is to excel.

At the present time, the main avenues open may be defined, broadly, as five in number, viz.: cable and telegraph engineering, including telephony; manufacturing; wiring work; central station supply; and consulting engineering.

Telegraphy possesses many attractive features, and there is always likely to be a steady demand for this class of engineer. But the good posts are filled up, and there is not the same rapid extension as in other branches; those starting now would probably find progress very slow compared with that in the classes named below.

Manufacturing offers very considerable scope, especially for the inventive faculty, and recent developments of the needs of central stations have raised this branch above the reproach of being little better than brass finishing, the work now undertaken being really heavy engineering, and calling for skilful design and the best engineering talent. Little doubt can exist that the importance of the work will greatly increase, and all kinds of general mechanical engineering will become part of the work of the electrical manufacturer. The ever-increasing number of applications of electrical energy to the needs of factories and workshops will contribute largely to bring about this result, and, in a few years, heavy railway work will almost certainly be included.

Wiring work may be taken as the antithesis of that last named, and, far from increasing in importance, it seems likely to diminish and settle down merely into a branch of plumbing. At one time, when the subject

was a new one, it engaged some of the best talent, but rules have now been formulated, and practice has become more or less stereotyped, so that there is little to attract an engineer. Of course, large buildings call for skill in design, but these are looked after by the consulting engineer, who formulates the scheme, the actual carrying out of which devolves still upon the wiring contractor and calls only for attention to well-known rules.

Central station work offers a most interesting field, and gives great scope for many different talents, besides being one of the most promising avenues to the highest positions in the profession. This branch is that which we shall have to consider in detail.

Consulting engineering, using the expression in its legitimate sense, is probably the most desirable, as well as the most lucrative, kind of work. The responsibility is great, the scope for inventive and constructive ability is practically unlimited, the position is one of independence from control, and the standing is of the highest. The term 'consulting engineer' is, however, one of the loosest application, and has been applied indiscriminately to able, conscientious engineers, to company promoters, to contractors' touts, and to failures in other branches. It is needless to say that only the first-named class is here referred to. To qualify for the distinction, years of hard work in one or several of the other branches are necessary, and no path seems more likely to lead to successful work as a consultant than that of a central station engineer, though the position may be looked upon as a goal that may be attained through any one of the classes of work named.

Returning to central station work as being that with which we are concerned, it will be found that it calls for a most liberal education, and involves nearly every kind of engineering, besides attributes rare to find, but nevertheless necessary to success, in many walks of life. Primarily, there must be a solid grounding of mathematics, general physics, and chemistry; there must also be a thorough training in steam and mechanical engineering generally, and in electrical science; while a knowledge of building construction, together with an acquaintance with surveying and levelling, is highly desirable, if not absolutely essential. Commercial knowledge must also enter as an ingredient in the composition of a successful central station engineer. To all this knowledge, which can be acquired by study, must be added tact and ability to manage men; these things come by intuition, and cannot be taught, except to some extent by experience; they belong rather to the heart than to the head, but they are essential, and no great measure of success will be attained without them.

What course should be pursued by a parent wishing to thoroughly qualify his son to be a central station engineer? First of all, let him ascertain that his son really has a natural inclination for the kind of work.

What has been said above is sufficient to show that a long and arduous training has to be gone through, and hard work, well-directed effort, patience, and ability are each and all necessary. There is no royal road, and it is futile for anyone to hope to attain a leading position in the profession unless he has some natural ability for it, and is prepared to find pleasure in his work.

A liberal education for the boy will be found of inestimable advantage to him in his career; some acquaintance with classics, a knowledge of one or more modern languages, and, above all, the ability to write English as distinguished from journalese (rare accomplishment!), together with a good grounding in mathematics, will best pave the way for his technical training.

School should be left when the boy is about fifteen or sixteen years old, and he should then be sent to an engineering college for three years. It is far better that his theoretical training should come before the practical, for not only is he at an age when the mind is most retentive, but his school habits of discipline and learning still cling to him. Moreover, when the practical training comes, he is better able to appreciate its value, and he notices many points that would otherwise escape him. Again, the rough surroundings in a workshop, that might be harmful to a mere boy, are comparatively innocuous to a young man.

In choosing a college, it must be borne in mind that what has to be produced is an engineer, not a mere electrician. For this reason, it is wise to select one of the older institutions which have stood the test of time, and in which some of the foremost engineers of the present day received their education. The cry for technical education has indeed produced numberless colleges, extravagantly equipped with costly apparatus, and magnificent piles have risen to give shelter to the students; but education does not consist in elaborate apparatus or fine buildings, and the result of a two or three years' sojourn in such places is apt to be very disappointing. The great fault appears to be that the student is allowed to specialise too soon, and the training given is too narrow and limited. The student is taught a great deal of electrical science, no doubt, and to carry out a number of elaborate experiments. He becomes imbued with an exaggerated respect for academical methods, and a fine contempt for the men with whom he comes in contact when he starts in a workshop or station. The products of such training are of little value in practical work; they look upon a central station as a kind of large-scale laboratory, and yearn to make interesting experiments in it. They have little or no appreciation of the commercial side of the work; they do not realise that, although a thing may not be the best scientifically, it may possess more than counterbalancing practical advantages, and that although an alteration might mean a slight gain in efficiency, it would not pay to make it. Such men either become disgusted by the daily routine and the sameness of their work, or they

develop into faddists or visionaries, carried away with every change in fashion and a prey to every novelty-monger.

The thought will naturally occur to many, whether it would not be preferable that the theoretical training should be acquired abroad rather than in England. At first sight, it would appear that this course has much to recommend it. The Continental technical schools have a high and, undoubtedly, well-deserved reputation, and, incidentally, a sojourn in them would enable a knowledge of one or more foreign languages to be acquired. There is, however, one most serious, if not fatal, objection: during his college days, a youth is making the acquaintance of those who will be his contemporaries throughout his career, and is forming friendships that will prove invaluable to him later on. His character is forming, and he is becoming known to the professors, and is getting a reputation among them for either good or ill. The foundations of his after-career are being laid, and his character at college will cling to him for ever. Now, if the years in question be spent abroad, golden opinions may be earned, but they will be wasted so far as advancement is concerned, because those holding them do not come into contact with the persons among whom the student is thrown. He returns to England unknown, and has to start afresh, and to make new friends with far fewer opportunities of doing so than he had at college. Another consideration must be referred to, and that is the danger of setting a lad fresh from school, and free from control, among the surroundings incidental to foreign life. How many promising young fellows can one call to mind who have returned to England moral wrecks and having their careers hopelessly blighted!

After the general engineering and scientific foundation has been laid, the student, on leaving college, should be articled as a pupil for, say, two years to an engineer of standing. The particular class of work undertaken by the engineer that should be sought is a matter for some difference of opinion, and doubtless it will have to depend largely on the opportunities offering at the time. Perhaps, on the whole, it is preferable for the student to be articled to a firm of steam-engine builders; this will ensure a thorough manual training, and, in addition, a knowledge of steam engines will be attained, which will be found of great value in the central station later on. Any kind of mechanical workshop where the work is sufficiently varied will suffice; it is not necessary that the business should be of an electrical nature, as it is manual dexterity that is sought, but if there be an electrical department attached, it will be very desirable to get an insight into dynamo building, especially armature winding.

It is essential that the pupil should be properly indentured to an engineer, who should be, if possible, a member of the Institution of Civil Engineers. An articled pupil takes a higher standing than one not articled, and to have entered the profession in this manner will be found most

valuable later on, especially when seeking admission to engineering institutions or societies. It is advisable that he should become a student of the leading ones as early as he can; he will then be able to attend their meetings, and will not only derive benefit from hearing the papers read, but will get into touch with persons whose acquaintance may be of value to him later on. He should specially make a point of attending the students' meetings, and should endeavour to contribute papers and take part in their discussions. By so doing he will learn much, and will differentiate himself from the crowd. He will find the magnificent libraries which are open to him of great value during the period of his college life.

So far the training has been such as to fit the student for any branch of civil engineering, though the bias has already been shown by special attention being given to electrical subjects; now, however, the general training must be abandoned for the particular, and the special branch desired must be decided on. The young engineer must go for a year, either still as a pupil, or as an unpaid assistant, to a manufacturer, to a firm of wiring contractors, to a consulting engineer, or to a central station.

It is to be regretted that there are not more central stations in which pupils are received. It would appear self-evident that central station work can only be learnt in a central station; but few of the large stations take pupils, the result being that very few men get a training in all branches; some have experience only of engine-room work, others of main laying or installation work, and when they have stations of their own, they find themselves at a loss in some departments. If possible, it is preferable to go as a pupil in a large station, the larger the better. If the engineer has a proper sense of his responsibility, he will arrange for the pupil to spend a portion of his time in every department, and the knowledge acquired will be varied and complete. Failing a large station, it is best to go as unpaid assistant in a small station, as, although everything is on a small scale, the experience is varied; whereas, if not a pupil, a man in a large station finds everything so subdivided into departments that his experience is limited to one small portion of the work, and, not being a pupil, he cannot expect to be shifted about, or be given facilities for varying the knowledge acquired.

The initial training is now complete, and a man trained in accordance with the foregoing recommendations will have little difficulty in obtaining a post as assistant in an important station, or the position of chief of a small one. If he be wise, he will prefer the former, for it is more probable that important positions in large stations will be filled up from the existing staff, than that men knowing nothing of the particular station will be imported.

The time suggested above is the minimum that ought to be given to each stage; an additional year as pupil in the station would be a great

advantage, and an extra year in a different mechanical workshop would be useful.

It will be seen that the education of a central station engineer is an expensive one, and occupies from six to eight years; but the same may be said of most professions in which good positions are to be attained.

Due allowance for the cost of training was not made when the industry was first started, and the salaries offered could only be described as ridiculous, but they were accepted in order that experience might be gained. Companies and corporations soon found, however, that to pay salaries in experience instead of cash was apt to be very expensive, and there is every indication that the sums paid are likely in the future to be more nearly proportionate to the services rendered. The salaries paid at present vary from £200 to £500 per annum for small stations, and from £800 to £2000 per annum in important stations, though £1000 per annum or above is exceptional. In some cases, especially in the smaller stations, the engineer also receives the premium, in whole or in part, of one or more pupils.

Central station engineers are divided into two distinct groups, namely, municipal, and those engaged by companies. Each sphere possesses advantages of its own, and it is difficult to say which is to be preferred; probably circumstances will determine into which the engineer drifts. Companies usually pay higher salaries than municipalities, and, as a rule, their engineers have a somewhat freer hand, though they are more liable to be restricted as regards capital for their schemes. On the other hand, some municipalities exhibit full confidence in their engineers and do not hamper them, and the tendency towards this wiser course is growing. The security of tenure of office in a municipal station is absolute, and the public position held is one of considerable importance. There is at the present time a distinct indication that considerable development will take place, and, instead of being merely engineer to the Electric Lighting Committee, the official will be electrical engineer to the municipality as a whole, and will have under his control the whole of its electrical undertakings, which will include, not only ordinary central station supply, but electrical tramways, and, possibly, the local telephony. On the whole, therefore, it would seem likely that, in the future, the position of municipal engineer will be the better one, as involving the greater responsibility. Another consideration is that municipalities show so great a desire to undertake the electric supply themselves, and, where a company already exists, to acquire its business, that municipal engineers are likely to largely preponderate numerically; but against this must be put the fact that there may be established in the near future very large systems of supply over areas covering hundreds of square miles of territory under the control of companies. Of course an engineer can readily change from one sphere to the other, and,

in all probability, will do so more than once in his career, but it is well to point out the respective advantages.

It is not intended to imply that the training just sketched out is the only one possible, or that positions of eminence cannot be attained by those working their way up from very different beginnings, but it is affirmed that it presents the best chances of advancement, and well qualifies a man for the work. It must not be lost sight of that the industry is rapidly becoming more settled, and that, although many persons holding good positions in it now have not had a training specially adapting them for the work, more will be required of their successors.

A word on the management of men may not be out of place before concluding this chapter. In the various departments of his work, the engineer will come across many different classes of men, from the engineer who has had a training similar to his own, to the common labourer. They will all require managing, and each will require some difference in his treatment, but there are leading principles which apply equally to all. Above everything, the engineer must be fair and devoid of favouritism; he must never try to take advantage of a man, for nothing is more resented than anything approaching sharp practice; and he must not pass over in one what he condemns in another. Again, nothing lowers a man in authority more than to lose his temper; no human being is perfect, but let it be remembered that each time command over oneself is lost, a step downwards is made that will take long to recover. A certain amount of dignity should be cultivated, so that each man, from the highest to the lowest, shall be afraid to take a liberty, but anything in the nature of what is so expressively termed 'side' is absolutely fatal. Nothing is more detestable or contemptible than to see a mere boy hectoring and bullying men two or three times his age. Many make the mistake of blustering and swearing at those beneath them; not only is this cowardly, but it degrades the person guilty of it to the level of the common workman; the men expect it of their foreman, who is of their own class, but not of a gentleman.

An engineer should ever be on the watch for merit in his men, so that he may single out the best for promotion. If he see one who is anxious about his work, and taking an interest in it for its own sake, let him mark him well, for such men are rare and are invaluable. Some persons are so short-sighted that they will actually resent a workman trying to do well and take a leading part, looking upon him as fussy and officious, and suspecting him of ulterior motives. How little do they know what they are throwing away!

CHAPTER III.

CENTRAL STATION SUPPLY AS AN INVESTMENT.

The business of supplying electrical energy from central stations is one which has passed through many vicissitudes. At its inception, it had to fight against the disrepute into which everything connected with electric lighting fell, in consequence of the speculation which attended the introduction of the industry. No data existed as to the cost of supply, and capitalists were without anything to guide them as to what the profits of the undertaking were likely to be; indeed it was doubtful whether a general supply on the lines of gas were even physically possible, leaving out of consideration altogether the financial side of the question. What served, however, to almost entirely drive away financial support was the onerous condition imposed by the Electric Lighting Act, 1882, by which the Local Authority was given the power to purchase the undertaking, without any allowance for goodwill, at the end of twenty-one years. Even with a well-understood and firmly established industry, it would be difficult to raise money on such terms; in the case under consideration it proved to be practically impossible. A few stations were established, but they were principally overgrown private installations, and their work was of a more or less temporary and tentative character.

In 1888 the Electric Lighting Act was amended, and the period of tenure extended from twenty-one to forty-two years. Immediately this alteration was effected, there arose a large number of supply companies, proving conclusively that it was the Act which had deterred investors from embarking in the enterprise, though, no doubt, the work done by the few pioneer companies that already existed had gone some way to establish confidence in the industry as one which might be expected to yield good profits. Besides this, a demand had been created by these companies which was far greater than they were able at that time to supply.

Very soon, however, a new and quite unexpected development set in. When the investing public showed that they anticipated a profitable return from the investment of their money in central station supply, and applied to the various Local Authorities for their assent to the establishment of the necessary works, these authorities arrived at the conclusion that the profits

might as well be earned for their ratepayers, and refused their consent, themselves applying for Provisional Orders. Many, no doubt, were influenced by the desire to avoid the establishment of a monopoly like that already existing in the case of gas, and others again, having their own gas works, wished to preclude competition with their municipal undertakings.

This spirit was very widely diffused, and the result was that the work fell largely into the hands of Local Authorities, and the tendency now undoubtedly is for municipal stations to be established, and for the companies, where they exist, to be bought out by the municipality. Inasmuch as this purchase takes place before the term provided in the Act, the company is able to make its own terms, and in many cases the return to the shareholders has been extremely good.

Looked at broadly, there is little doubt that, given a committee of able business men, content not to interfere in technical matters, and a competent engineer, a municipality is able to produce electrical energy in a given district more cheaply than is a private company.

In the first place, there is no expense for promotion of the company, nor for directors' fees. Secondly, the interest to be paid on capital is very considerably less than that expected by an investor in this class of business, unless there be a desire to make a profit to be applied in relief of the rates. The cost of the plant will on the whole probably be less, as, although in some cases contractors charge more to a corporation than to a private company, on the other hand, many companies are so intimately associated, at all events at their inception, with manufacturing companies that their choice of plant is very greatly restricted, and the prices paid are not those that would obtain in the open market. Again, a municipality is in a much better position than a company as regards the laying of mains; it can do the work more cheaply, and need only pay the cost price of reinstating the surface of the ground.

The question as to whether a central station will yield a profit in a given district depends upon many considerations. The density of the demand is one important factor, the length of user of the supply is another. Local conditions, such as cost of coal and labour, will largely affect the cost of production, and the capital outlay will vary greatly according to the nature of the system of supply necessitated by the character of the district, and it will be dependent upon the cost of the site for the works.

It may be taken for granted that, if an efficient supply be given, there is no question whatever as to the desire of the general public to use it for all purposes. Electric lighting and driving are so immeasurably superior to other illuminants and motors, that it is merely a question of the cost as to whether the supply is utilised. The cost consists partly of an annual charge for the energy and lamp renewals, and partly of the first cost of putting up the necessary fittings. Both depend greatly upon local conditions. The cost of energy to the consumer will be affected by the cost of its production,

and by the method of charging adopted by the suppliers; both these matters will be very fully discussed later. The cost of fitting up will be governed to a very great extent by the conditions of tenancy of the houses and shops. The wiring is a fixture and becomes the landlord's property at the expiration of the tenancy; hence, if the leases be short, the money paid has to be written off in so few years that the annual cost is very high. This consideration operates to a most serious extent to restrict the demand from private houses. It is less important in the case of shops, because the direct money saving effected by the use of electric light, owing to diminished deterioration of stock and of decorations, and the gain through the advertising value of the better illuminant, suffice to counterbalance a much larger expenditure than would be justifiable for domestic lighting.

The price of gas and its quality will go far towards determining the extent of the demand for electrical energy, and it varies between wide limits in different localities.

The fact that so many local conditions enter into the question renders it impossible to lay down any hard and fast rule, and to say that a station will be profitable in a district of a certain area, or in one having a certain number of inhabitants, or class of population.

Each case must be decided on its merits, but, broadly speaking, the greater the number of possible consumers per square mile the better the chance, *cæteris paribus*, of profit. Where consumers are few and far between, the expenditure upon mains, and the loss of energy in them, become unduly large, and if a certain point be passed the return may be insufficient to cover the interest charges and the cost of waste, and in such a case the station cannot pay. Again, the greater the length of user, the longer the plant and mains are occupied, and, therefore, the more productive is the capital and the less is the cost for charges. This consideration is perhaps the most important one in the financial success of the undertaking, as, besides operating in the direction stated, it enables the price to be reduced to long-hour consumers, and so allows keen competition with gas or other agents, and very largely increases the demand for electrical energy. Typical examples of long-hour user are street lighting, motive power for tram traction or for factory driving, charging of secondary batteries.

In nearly all important towns, a well-designed and well-operated station may be expected to yield a profit, and in small towns, and even in villages, it will do so in very many cases. In the case of small towns, and especially in that of suburbs of large ones, success may often be secured by combination of a number together; for just as a saving in cost of production is effected by concentrating a large number of independent small sets of generating plant in a central station, so greater economy may be effected by supplying a number of small districts from a single large station, if they be not too far apart.

The latest statistical returns available are those for 1898. These show that for that year the capital invested in central station supply was £14,975,741, of which £7,996,591 was expended by companies and £6,979,150 by municipalities. The average profit earned by the former was 5·51 per cent., and by the latter 5·55 per cent.; the price obtained by the companies was, however, over 26 per cent. higher than that charged by the municipalities.

Taking the returns of forty-four companies having an aggregate capital of £8,284,212, the loan and debenture capital, amounting to £2,255,289, yielded an average rate of profit of 4·46 per cent. The preference capital, aggregating £1,341,280, produced an average return of 5·90 per cent., while the remaining £4,687,643, consisting of ordinary shares, paid 5·57 per cent.

Of the whole capital, only £948,252, or about 11½ per cent., was unproductive. The rate of dividend paid on the ordinary shares ranged from 2 per cent. to 14½ per cent.

The shares of most of the London companies are quoted at a substantial premium, many being 50 per cent. and some 100 per cent. above par.

These figures show that as a whole this branch of industry pays a good return on the capital invested, while, in certain cases, the profits are very great indeed. The business is now firmly established, and it seems probable that the success will not only be maintained, but augmented as the stations increase in size and the demand for energy grows, an important factor being the advent of electric traction.

CHAPTER IV.

THE ESTABLISHMENT OF A CENTRAL STATION.

WHEN the establishment of an electric supply in a given district has been decided on, there are many points that must be taken into consideration. Among the most important are the choice of a site for the generating works; the system of generation and distribution to be adopted; the magnitude of the initial installation; the streets to be scheduled as compulsory, that is to say, those in which a supply must be given within two years from the date of the Act confirming the Provisional Order; the permissive area; the initial price to be charged. Most of these points will be dealt with fully in separate chapters, while this one will be limited to a general view of the subject.

Into the legal procedure necessary to obtain statutory powers to supply electrical energy, it is not necessary here to enter. Suffice it to say that a special Act may be obtained, or, as is much more frequently the case, a Provisional Order may be obtained from the Board of Trade under the Electric Lighting Acts. In the case of a company, the assent of the Local Authority in whose district the supply is proposed to be given is required, but, under special circumstances, the Board of Trade may dispense with such consent. As a matter of fact, this latter right is rarely exercised, and the Local Authority would only be overridden if it were acting in an unfair manner. The Act expressly lays down the principle that the granting of a Provisional Order confers no monopoly on the body to whom it is granted; but the practice has hitherto been that a Local Authority efficiently working its Order has been free from competition, and in most provincial towns in which a company has been at work under like conditions, the same privilege has been enjoyed; but in London most companies have had to face competition, the endeavour having been made to grant collateral powers to two companies, one of which employs a continuous, the other an alternating, system of supply.

The suppliers, who are known as Undertakers, are granted certain statutory powers, enabling them to purchase and use lands, to break up streets, to divert pipes belonging to other companies, and to enter upon premises of consumers. In return for these privileges, the Undertakers incur certain

obligations: they have to lay mains in specified streets; to give a continuous supply of energy, and to maintain given conditions as to pressure, etc.; to keep their mains and apparatus in efficient condition; to take precautions to secure the safety of the public, and to avoid damage to the property of other companies and authorities, in particular of the Postmaster-General.

It must be borne in mind that the undertaking ought to be so designed and carried out that, not only shall it be a financial success eventually, but that it shall pay its way at every stage of its development. The reproach is often brought against engineers that they have designed their works on too small a scale, and have had to make extensive alterations and replacements after only a few years have elapsed; and, no doubt, this is to a certain extent true. On the other hand, what has been the result of laying down the plant on too ambitious a scale? In some cases complete disaster, in others years of unremunerative working. It may be far sounder financially to lay down a small works that will yield a handsome return on the small capital immediately, and, after a few years, when the business is firmly established and large profits are being earned, write off the small plant that has become obsolete, than to at once sink a large capital in machinery, much of which stands idle for several years, and be unable to pay a dividend, or even cover working expenses. In the latter case, the large demand which was anticipated, and which the extensive machinery was destined to supply, is checked and prevented by the fact that the provision of this very machinery has made the lowering of the price to a popular figure impossible by unduly burdening the undertaking. It is too often assumed that the large demand would have existed in any case, whereas it is the outcome of the economical working of the plant adapted to the needs of the district at the time.

It must not be thought that small plant is advocated; on the contrary, it is necessary that proper foresight should be exercised, and it is on the skill of the engineer in gauging the needs of the district that success will in part depend.

It is well not to be too niggardly in the laying of mains, for there is no canvasser to be compared with the cable which actually passes a man's door, and the more streets that can be tapped, the better is the chance of the generating plant having something to do.

A most important element of success is the adoption of a liberal policy. It is not advisable for a company to insist upon its full legal rights under all circumstances. Especially is this the case with regard to the laying of mains. The Undertakers are entitled to charge a consumer for so much of the service line as he requires which is beyond 60 feet from the existing main, and he may be legally charged for it. In the majority of cases, however, it will pay the Undertakers far better to lay a distributing main instead of the service line, give the connection free, and trust to other consumers beyond or adjacent to the consumer in question being obtained; they will

rarely be disappointed. If the opposite course be adopted, and a charge be made, the Undertakers are almost certain to have applications for supply that they can conveniently give through this service main, and the consumer will then feel aggrieved that the main, for which he paid, is being employed to supply current to others who have made no such payment, and a feeling of irritation and hostility against the company is raised, which does far more damage than the money received for the cost of the line can make up for.

Another obstacle to progress which should be avoided, is the charging of excessive rents for meters, transformers, transformer chambers, etc. A sum for meter rent is perfectly defensible, as under the Act the consumer has to provide himself with a meter, and if he like to arrange with the Undertakers to relieve him of the trouble of purchasing it and maintaining it in good order, it is only fair that he should pay them for the convenience. At the same time, consumers are not always logical, and, in many cases, there can be no doubt that meter rents retard development. Rent for transformers and their receptacles stands on a totally different footing; it is doubtful whether it can be legally claimed, and it is manifestly unfair. There can be no good reason why a consumer should pay for apparatus, the only use of which is to save money for the Undertakers by enabling them to work with smaller mains. In case of competition with a low pressure company, this one item will often turn the scale in favour of the latter.

In designing the works, it must ever be kept in sight that reliability, that is to say, continuity of supply and steady pressure, will do more than anything else to secure a good demand. It will pay to make everything, including even efficiency, subservient to this. Undoubtedly duplicate steam mains mean increased running costs; duplicate plant, duplicate feeders, alternative routes for distributing mains, mean increased capital expenditure; but these precautions are well worth the money, and their cost will be as nothing compared with the actual money damage inflicted on the Undertakers by a cessation of supply for, say, ten minutes, or even momentarily, several times in the course of a year. One or two such breakdowns will retard progress for years, by creating the impression that, however desirable the supply may be in other respects, it is not reliable, and cannot be depended on solely to the exclusion of gas.

In these general remarks, another point that may be referred to is the necessity for establishing at the outset a high standard of work as regards the wiring of consumers' premises. Definite rules should be made and strictly enforced by careful inspection and firmness. Not only is the task of giving a satisfactory supply rendered easier, but the chances of fire and of needless interruption by failure of the consumers' own apparatus diminished. It must not be forgotten that the non-technical public concerns itself little with causes, and if the light go out or the motor stop, the consumer will not inquire whether the fault lies with his own fuse or installation, or with the

supply; he will simply say, "Electricity is unreliable; I must go back to gas;" and, after all, it is matter for small wonder if he fail to lay the blame on the right shoulders; the Undertakers ought to have safeguarded him from the possibility of bad work. Again, if a fire ensue, it is certain to be put down to the dangerous nature of the mysterious agent electricity, and no amount of explanation will remove the impression.

A pitfall which should be avoided equally by Companies and Local Authorities is the temptation to undertake wiring themselves. It is a fatal mistake in nearly all cases for them to do so. In the first place, the direct effect is to stir up a feeling of animosity between themselves and their best friends, the wiring contractors, who are in effect an army of canvassers; secondly, it militates against the independent position that the Undertakers should occupy, as they are liable to the suspicion of unduly favouring their own work; thirdly, they unnecessarily increase their responsibility; and lastly, they embark in a business which is notoriously one in which competition is most keen, and the profits of which are often small, even in the hands of those who devote their whole attention to it, while the average station engineer rarely has the time required for properly attending to the detail work. The only conceivable case in which it might be desirable for the supply authority to undertake the work is in very small and remote towns and villages, in which there would be insufficient business to maintain contractors, but such cases must be extremely rare, if they exist at all.

Notwithstanding the above, it is very desirable that the Undertakers should take cognisance of the details of the work; but the powers given them under the Electric Lighting Acts and Provisional Orders are quite inadequate for the purpose. Further reference to this will be made in a later chapter, but here it may be said that one extremely good way of acquiring the necessary *locus standi*, and of avoiding the objections enumerated above that arise if the Undertakers carry out the wiring, is for the central station engineer to become consulting engineer to the consumer in his private capacity.

When the Authorities have decided to establish electric supply in a district, two courses are open to them. They may either appoint a consulting engineer to design, and superintend the erection of, the work, subsequently appointing a resident engineer to take charge of the running and management; or they may, in the first instance, appoint the engineer who is to manage and run the station, and allow him to prepare the designs. If the consultant has had actual practical central station experience, the former is, perhaps, the safer course, for he will have designed a number of stations and will know better what to avoid than a man who is perhaps designing one for the first time. On the other hand, once the plant is erected the consulting engineer's responsibility is practically at an end, whereas if he had to run the station it would be but beginning. Again, seeing that consultants'

fees usually take the form of a percentage on the capital expended, there is every temptation to make the capital as large as possible; whereas, when the other method is resorted to, there is every inducement for the engineer to keep down the capital expense, since his remuneration is usually independent of its amount, and he well knows that the ultimate success of the undertaking will depend to a very large extent on the amount of the standing charges.

On the whole, the course to be chosen depends greatly upon the magnitude of the undertaking. If it be such as to admit of the payment of a good salary in the first instance, and the prospects of development are such as to attract central station engineers of good standing, then the best course would seem to be to engage an engineer at once to run the station and to let him design and carry out the whole scheme. On the other hand, if the scale of operations is comparatively small, then the consulting engineer should be employed, and a man of more moderate attainments be engaged to carry on the work along the lines laid down.

Both methods have been tried and have given good results; but there is another course which is sometimes followed that can hardly be attended with any but disastrous results, namely, the dispensing with an engineer and the issuing of invitations to contractors for a complete scheme. It must surely be obvious to anyone that a contractor's business is to sell his wares and push his own trade, and that his proposals will primarily be devised to benefit himself, though if he can incidentally furnish a scheme well suited to the requirements of the district, he will doubtless do so. It is usually municipalities who are guilty of this unwise course, but in many cases companies are subject to a similar evil in a somewhat different form, it being not unusual for a supply company to be promoted by a manufacturing company, in which case the unfortunate central station is compelled to be furnished with plant by the promoting company.

It is most important that the engineer should control and direct the undertaking, subject, of course, to the Board of Directors or Municipal Committee, as the case may be. The problems involved are often of considerable complexity, and can only be dealt with properly by one who has had an engineering training. If the engineer be fettered by having his actions controlled by a general manager or secretary, he will naturally lose heart in his work and care little whether it succeed or fail.

CHAPTER V.

SYSTEMS OF SUPPLY.

THE systems of supply proposed and possible are numerous, but it is only intended to describe those actually at work or likely to be employed, and which are adapted to furnishing energy for all purposes to a number of distinct consumers requiring very different amounts. Obviously, the conditions to be fulfilled are very different from those existing when energy has to be conveyed between two definite spots, and many additional considerations have to be taken into account.

It is exceedingly difficult to find a satisfactory basis for classification, since there is an essential difference between the system of generation and the system of distribution, and, while different considerations determine the choice of the two, they are nevertheless so intimately connected that it is impossible to describe one without the other. It will, perhaps, be found most convenient to base the classification on the systems of generation.

Various methods of classification may be adopted, but the vital distinction is between alternating and continuous current. These two main groups may be further divided, each according to the pressure, into low, high, and extra high pressure, while alternating may be further subdivided into single-phase, two-phase, and three-phase.

It is assumed that the reader is familiar with the properties of continuous and alternating currents of the various types enumerated; we are only concerned here with their application to general supply. From this point of view, the essential difference between them lies in the fact that alternating can be altered in pressure conveniently, cheaply and efficiently, while continuous current involves the use of moving machinery for the purpose. When we come to consider the question of distribution, we shall see that there are other differences between the two which are most marked and of great importance.

High pressure is defined by the Board of Trade as follows:—"Where the conditions of the supply are such that the pressure may at any time exceed 500 volts if continuous, or 250 if alternating, but cannot exceed 3000 volts whether continuous or alternating, the supply shall be deemed a high pressure supply." When the pressure cannot exceed the inferior

limit of high pressure, *i.e.*, 500 volts if continuous, or 250 volts if alternating, it is known as 'low pressure,' and when it exceeds the upper limit of high pressure, *i.e.*, 3000 volts, either continuous or alternating, it is deemed by the Board of Trade an 'extra high pressure' supply.

By low pressure supply is usually understood a supply in which the current is generated at low pressure, and the installations of consumers are connected directly to the generators. Under such conditions, the pressure has not to be altered, and hence the principal advantage of alternating current is inoperative; from this it follows that continuous current is almost universally generated when low pressure is employed.

Nothing can be simpler than this system. It is shown diagrammatically in fig. 1, in which the dynamo, D, furnishes current directly through a pair of wires to the lamps and motors, L, A, M. Other arrangements involving the use of more than two wires, and therefore less simple, are

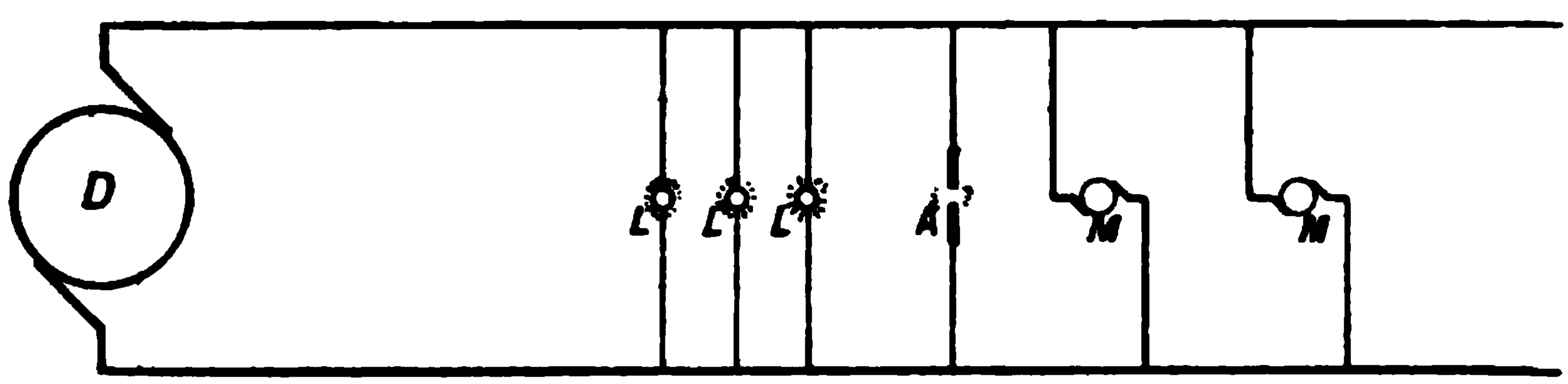


Fig. 1.—Low pressure supply, continuous current.

usually employed; these are fully described under the heading of Distribution (see page 26 *et seq.*; and Chapters XVIII. to XXI.).

The details of low pressure generation will be entered into later on. In this classification it need only be said that continuous current dynamo machines present few, if any, difficulties when the pressure does not exceed 500 volts. The wear and tear of the brushes and commutators forms the chief item, but in well designed machines, carefully looked after, this need not be great, and the problem is an easy and straightforward one.

Although, by definition, any pressure above the inferior limits assigned is high pressure, it is not usual in practice, if high pressure be employed, to adopt any pressure lower than 1000 volts, or more usually 2000 volts. Unlike the case of low pressure, both continuous and alternating current are employed, though the latter is much more largely used at present on account of the very great advantages it presents. Continuous current is, however, coming into considerable favour, and in all probability its use will be largely extended. The chief advantages of alternating current are the ease with which the pressure can be varied, as already referred to, and the extreme simplicity of the generators. There is no necessity for a commutator, and the elimination of this not only greatly cheapens the machine, but obviates the danger of breakdown from the current flashing

round on the surface of the commutator; further, as the simplest of brushes are used, the exact position of which is immaterial, there is but little risk of the attendant being fatally injured. Moreover, it is possible to radically alter the construction of the machine, and adopt a stationary armature and revolving field magnets. The advantages of this are enormous, for the portion subject to high pressure is relieved from the mechanical stresses incidental to a revolving body, and the liability to breakdown is thereby greatly diminished; while complete safety to life, so far as the generator is concerned, is secured by the entire high pressure portion being continuously insulated, no brushes being included in the circuit. The only brushes are those delivering the low pressure exciting current to the magnets.

Inasmuch as current must, except in special cases, be supplied to consumers at low pressure, it follows that their installations cannot be connected directly to the high pressure generators, and there must therefore be

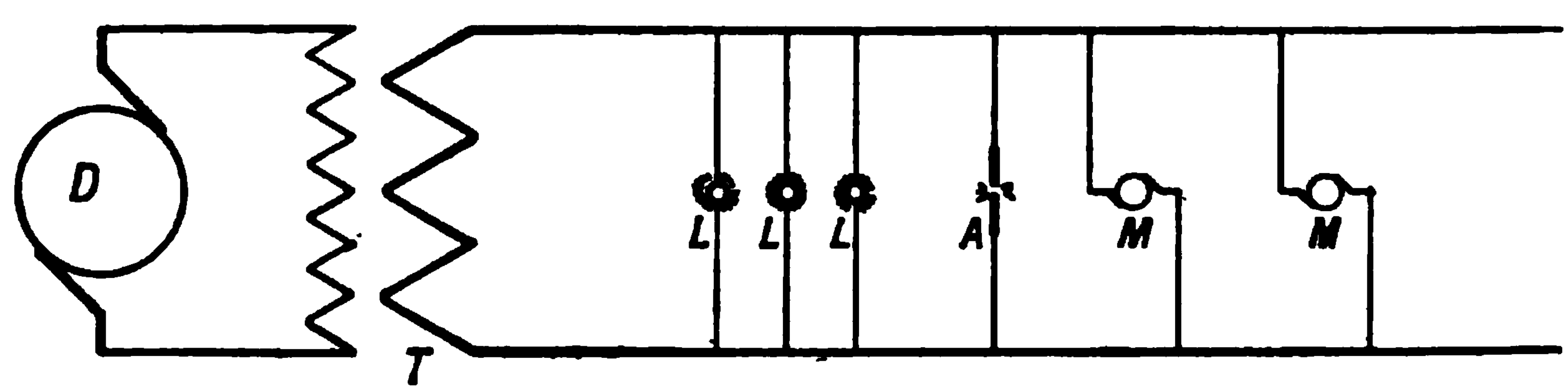


FIG. 2.—High pressure supply, alternating current.

interposed some device for lowering the pressure. For this reason, if for no other, high pressure working is necessarily less simple than low pressure, while the difficulty of insulating the conductors, and the danger to life, necessitate precautions which further increase its comparative complexity.

The simplest form of alternating high pressure supply is shown in fig. 2, where D is the alternator generating, say, 2000 volts, T a transformer lowering the pressure to, say, 100 volts, and L, A, M consuming devices. The generators deliver their current into the high pressure mains, which are entirely self-contained, and are not connected to any consumers' apparatus. The current from the high pressure main is taken into the primary coils of transformers, which may either be of small size and be distributed over the whole area of supply, being fixed in the houses of consumers, or they may be large and be buried under the streets, and their secondary coils feed a number of consumers; or, again, they may be grouped together in sub-stations, each of which feeds the transformed current into a system of low pressure mains supplying a considerable number of consumers.

The difficulties of generation are not great, the problem of efficient insulation being rendered comparatively easy for the reasons above stated. There is some difficulty in connection with the running of several machines in parallel on the mains, but this is not serious, except in the event of breakdown of a

machine, when the remainder may be thrown out of synchronism. The chief drawback, apart from questions of distribution, lies in the fact that the primary coils of the transformers absorb current when the secondaries are open, and since this waste is continuous the aggregate amount is very large. Various expedients have been resorted to to diminish this, but they all involve expense. At the present time single-phase alternating current is exclusively employed in this country, but on the Continent and in America multi-phase is largely used, and it is about to be tried in Great Britain.

Continuous current high pressure supply is not so varied in the manner in which it is carried out as alternating, since the transformers cannot be placed in the houses of ordinary consumers, nor can they be buried underground; they are thus of necessity always fixed in sub-stations. Fig. 3 shows diagrammatically the arrangement, D being the dynamo, M G the transformer, which in this case comprises in its simplest form a dynamo machine having

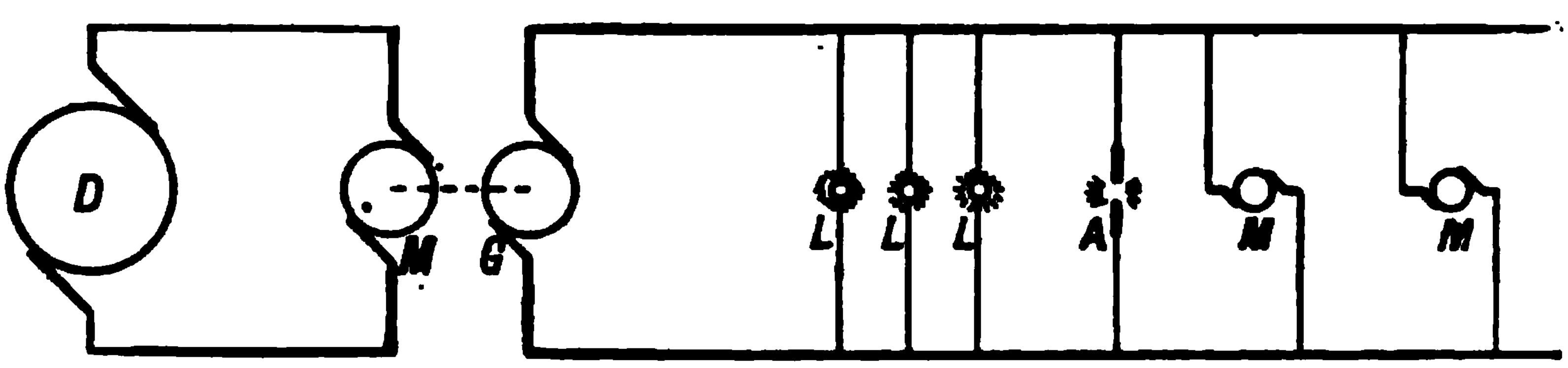


FIG. 3.—High pressure supply, continuous current.

two windings on its armature, which revolves in a simple field, one being fed with high pressure current and revolving as a motor, the other generating low pressure current which it gives out to the consuming devices, L, A, M.

When this system was first introduced, a pressure of 1000 volts only was attempted, but the success attained led to the construction of apparatus for 2000 volts, which is also running successfully, though it cannot be managed with such ease as alternating plant for equivalent pressure. Quite lately continuous current transformers have been built for 3000 volts, but their use for this pressure is not likely to be extensive.

The chief difficulty lies in the insulation of the revolving armature and of the commutator. Further than this, as already indicated, there is danger that the insulation between the segments of the latter may be impaired by a film of dirt, or of dust from the brushes, and the current may flash round from brush to brush. Unlike that of an alternator, a continuous current armature is difficult and costly to repair, and the burning out of the commutator of a large continuous current generator means, to all intents and purposes, the destruction of the machine, and the repairs would occupy much time and involve great expense. For these reasons, there must always be a large element of risk of breakdown, and to life, with high pressure continuous current, but, as a set-off against this, it has the important advantage over

alternating, that no idle current is absorbed by the high pressure circuits, while it enables continuous current to be distributed to consumers, which, as we shall see later, is a material consideration.

With both systems of high pressure, constant pressure is now always employed; the series systems, by which the transformers were connected in series with one another, a constant current being maintained through them, having quite gone out of use for central station purposes.

Extra high pressure differs from high pressure only in degree, all the difficulties being necessarily accentuated.

Alternating current is, practically speaking, exclusively employed, although it would be quite feasible to use continuous current if it presented sufficient advantages to counterbalance the drawbacks. It would probably be necessary in that case to transmit at constant current instead of constant pressure, and in Switzerland such a system is actually at work for trans-

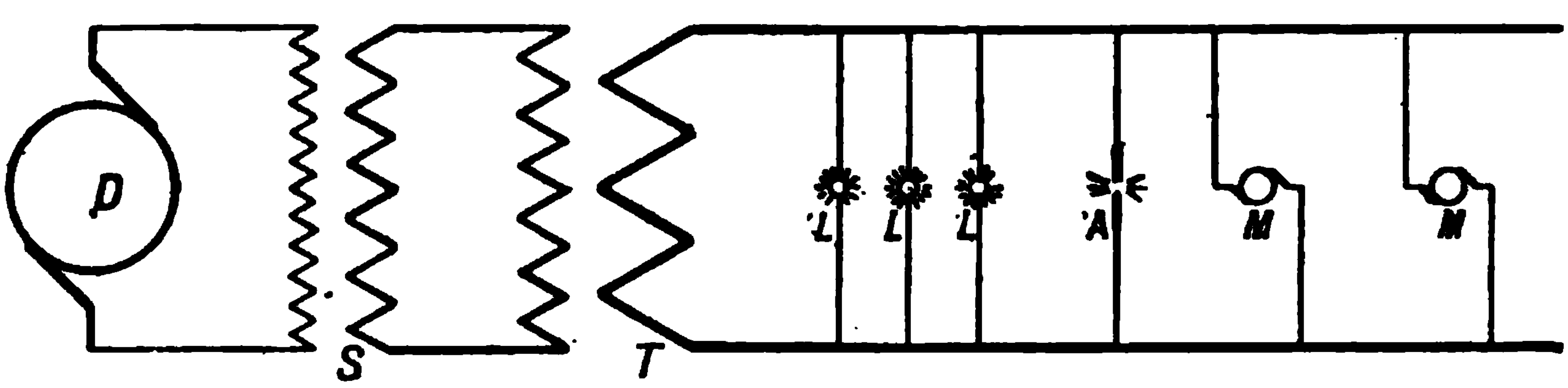


FIG. 4.—Extra high pressure supply, alternating current.

mitting energy for motive power, but great complications would arise if the arrangement were adopted for general supply.

It is usual to employ a double reduction of pressure, the extra high pressure current being taken to sub-stations and there transformed into high pressure, after which it is dealt with by any of the methods described above. The arrangement is shown in fig. 4, where D is the generator, S a transformer in the sub-station, T the consumer's transformer, and L, A, M consuming devices.

In some cases the extra high pressure current is not generated direct, but at a more moderate pressure, and is then transformed up for transmission to the sub-stations.

Another modification may be employed with either high or extra high pressure; it comprises a combination of alternating and continuous current. The current generated is alternating, and it is transmitted to sub-stations, where it is either taken direct or through transformers to alternating current motors, which are coupled to continuous current generators, or it is first transformed to low pressure, and the low pressure current is passed into the armature of a continuous current machine by means of rings connected to appropriate points in the winding; continuous current is then taken off from a commutator attached to the same armature. A machine arranged in this way is known as a rotatory converter. The two arrangements are

shown in figs. 5 and 6 respectively, the particular kind of alternating current indicated being three-phase. In the former D is the generator, M the alternating current motor, G the low pressure continuous current generator; in the latter D is the generator, T a transformer, R the rotatory converter; L, A, M being consuming devices in each case.

The system has been used abroad for general supply, and in Dublin and

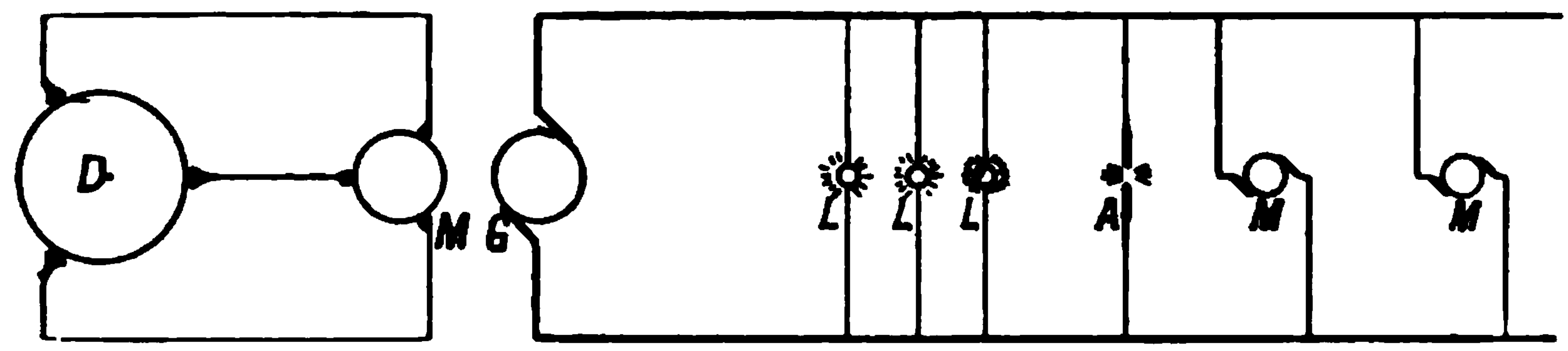


FIG. 5.—High or extra high pressure supply, alternating and continuous currents with motor-generators.

Middlesbrough for tramways. It is a most important one, and will be fully described later on.

The foregoing brief description will give a general idea of the various systems of generation and transmission; we have now to consider, with equal brevity, the methods of distribution. The function of distributing mains is to receive the current brought by the feeders to different fixed points, and to deliver it into the service lines of consumers at a large number of

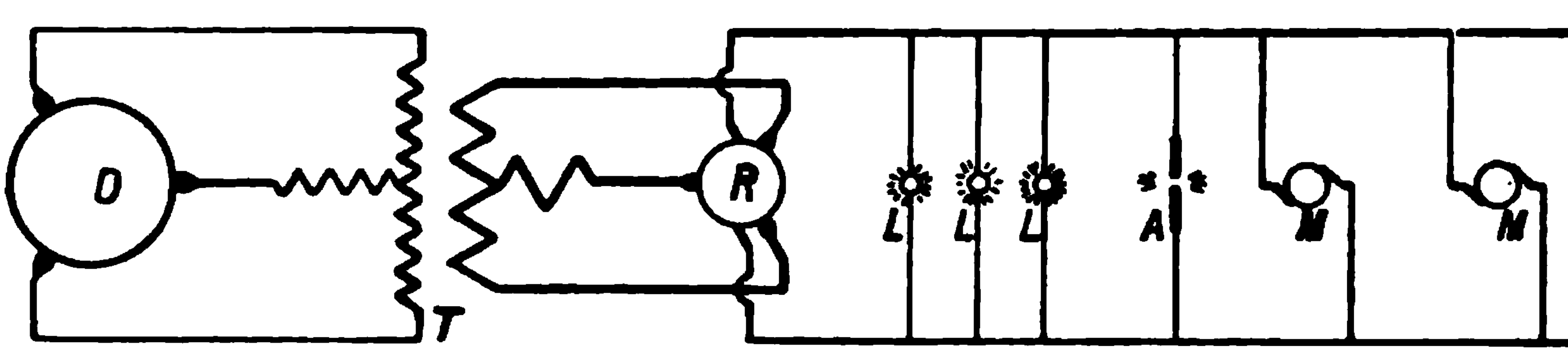


FIG. 6.—High or extra high pressure supply, alternating and continuous currents with rotatory converters.

points, dispersed over the whole area surrounding the feeding points. When a number of such mains are interconnected, they form what is known as the network or canalisation. This network is of the utmost importance, and much depends upon its design.

Although the system of distribution adopted necessarily depends upon the system of generation, it may well be considered on its merits, and apart from the question of the manner in which the current is brought to the various points of reception, for it is quite possible that the same network may be fed by totally different methods, at different points, according to the geographical position of those points.

Before considering the network in detail, the systems of distribution available must be described.

Distribution may take place either at high pressure or at low. For a long time the former found considerable favour, and for large, sparsely populated areas it is likely that it will continue in use for some time. Owing to the necessity for moving machinery with high pressure continuous current, this kind of distribution is only employed with alternating current. Its only recommendation is that it enables mains of light section to be used, while its drawbacks are so great that in districts where the demand is at all large, or the consumers at any except very considerable distances apart, it is being abandoned. The principal objections are the very low efficiency caused by the idle current in the transformers already referred to; the inconvenience of providing the space required for housing the transformers; the nuisance caused by the humming noise they give out and the amount of heat they dissipate; the danger of bringing the high pressure service lines into consumers' premises; and, finally, the inconvenience from the supply having to be stopped whenever joints have to be made for the purpose of connecting a new consumer to the main.

For the reasons enumerated, low pressure distribution is nearly always adopted, and the current supplied to consumers may be either alternating or continuous. The comparative merits of the two will be fully discussed later on; they are both distributed in the same manner.

The simplest form of distribution is the two-wire, in which the current is fed into the network at the pressure at which it is to be used, and the installations of the consumers are connected to two service lines, directly attached to the two conductors forming the distributing main.

Since, by the regulations of the Board of Trade, no consumer may be supplied at a higher pressure than 250 volts, and since, apart from such regulations, there are difficulties attending the use of a higher pressure than this, it follows that the pressure of distribution in this manner is extremely low. Obviously, the higher the pressure can be made the better, for, not only will a large economy in the cost of mains be effected, but the variations in pressure will be greatly diminished.

To secure this higher pressure, the system of multiple-wire distribution, invented by the late Dr John Hopkinson, F.R.S., was introduced. In this system the installations of consumers are divided into groups connected in series with one another, additional conductors being laid to connect the isolated consumers together, and so enable the groups to be formed.

The most common form of multiple-wire distribution is the three-wire, in which two groups only are placed in series, while the furthest point to which the principle has been pushed is the five-wire, where there are four groups. Figs. 7 and 8, showing the three- and five-wire systems, will make the arrangement clear. A pressure equal to that at which the consumers are supplied is maintained between A and B, and between B and C; or, in the case of the five-wire system, between A and B, B and C,

C and D, D and E. Now, it is obvious that, if there be the same number of lamps on each circuit, so that each takes the same current, there will be on the whole no current flowing to or from the feeding point along the intermediate conductors, though necessarily current will flow in those portions connecting the several members of a group of consumers together. Hence

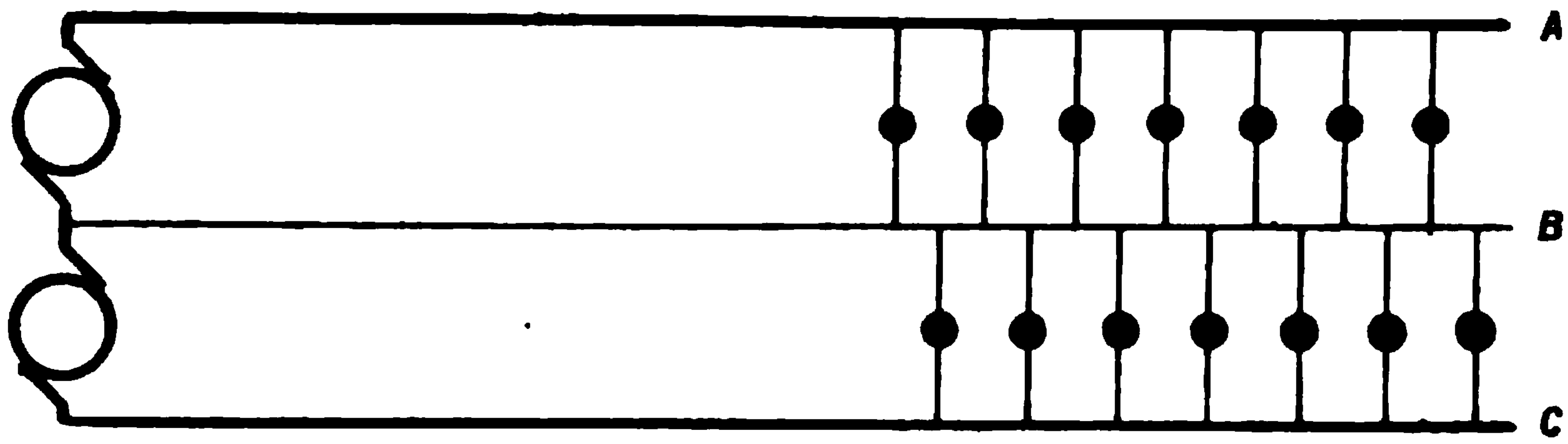


FIG. 7.—Three-wire system of distribution.

the intermediate wires might be cut at the feeding point when all circuits are equally loaded, or balanced, as the state is usually denominated. Next, suppose the circuit of one side of the three-wire system were open, then as much current would flow down the intermediate wire as down the outer. Both the cases named are extreme, and between them various conditions of balance

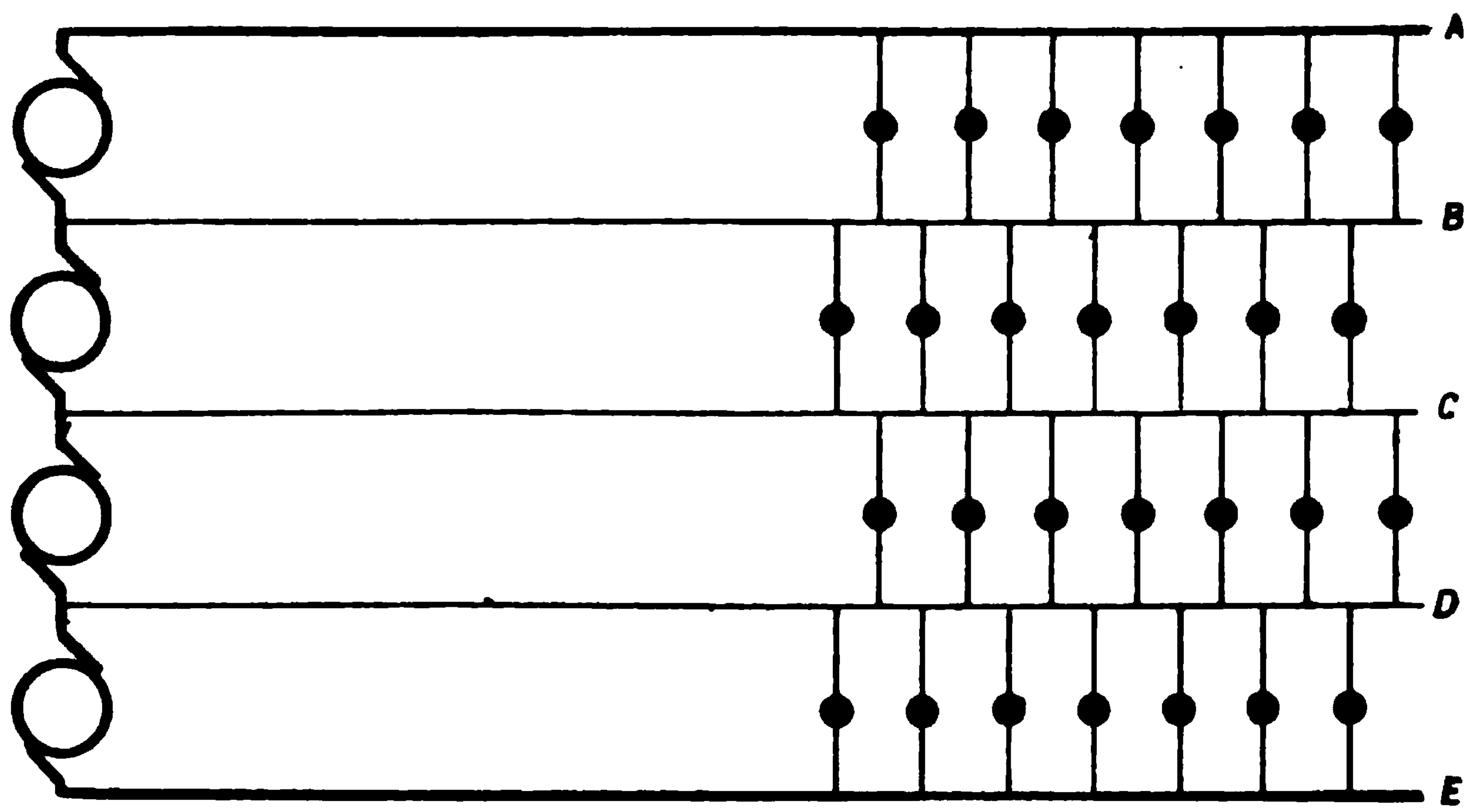


FIG. 8.—Five-wire system of distribution.

may exist; if care is taken to ensure the balance being always good, the currents transmitted by the intermediate wire or wires will be small compared with those in the outers, and they may therefore be of much smaller section.

It will be seen what an enormous saving is effected by the use of the multiple-wire system, for, in effect, distribution is carried out at twice or four times the pressure, according as the three- or five-wire system is employed, and this without necessitating any transforming device of any

kind. In consequence of these advantages, the three-wire system is almost universally employed for distribution of both continuous and alternating current. The five-wire has not come into extensive use, for reasons that will be given later on.

The arrangements of the network may vary greatly. It may be divided into a large number of small networks, each fed by a separate feeder, or into several, each fed by a group of feeders; or it may be one large system into which the whole of the feeders deliver current. Considerable difference of opinion exists as to the best arrangement, and it naturally varies with the district served; the matter will be discussed at length later on.

Most of the relative advantages of alternating and continuous current, so far as generation is concerned, have already been pointed out; there are, however, others to which reference must be made.

So far as switching operations are concerned, alternating currents are much easier to deal with at high pressures than continuous, the arc drawn on rupturing the circuit being much less serious and much less persistently maintained. For low pressures, the same holds good, but the disparity is much less important, owing to the fact that it is easy to apply a magnetic device for blowing out continuous current arcs, an arrangement impossible with alternating currents.

As regards transmission of current, alternating current possesses the important advantage that if leakage take place there is no danger of electrolytic action ensuing in connection with underground pipes or structures.*

When the two classes of current are compared for distribution purposes, the advantages are greatly in favour of continuous current.

For all purposes of consumption, continuous current is as good as alternating, with perhaps the solitary exception of electric welding by certain processes, while it is undoubtedly superior to it for arc lamps, and for motors in which a variable speed is required; for some purposes, such as electroplating, charging secondary batteries, and certain electro-chemical industries, it is indispensable.

Leaving the consumer's point of view, and turning to the point of view of economy and convenience of supply, there are equally cogent reasons in favour of continuous current. In the first place, it admits of the use of batteries, and so enables the load on the generators to be equalised over the twenty-four hours, and also relieves them from momentary shocks when many motors are at work, securing also better regulation of pressure. It is true that with alternating systems batteries can be used through the intervention of a motor generator, but for maximum economy it is essential that they should be kept as close to the consumer as possible in the chain of trans-

* This is the view generally held, but experiments recently made tend to show that alternating current does not give complete immunity from electrolysis.

mission. Moreover, the capital cost of batteries is already high enough, without adding the cost of an equivalent capacity of motor generators. Certainly batteries are at present too costly to admit of their use on a sufficiently large scale; but even if this be so at present, it is an advantage that the system should be so laid down as to admit of their use later on, if, as can hardly be doubted, the cost should be reduced by improvements or discoveries.

Facilities for the use of batteries is not the only direct advantage of continuous current. By its use the choice of mains is left quite unrestricted, since the only loss in the conductors is that due to resistance, and there is no danger of causing disturbance to telephone lines.

The vibration inseparable from alternating currents gives rise to troubles from which continuous current apparatus is free. Thus, fuse connections are apt to become loose, causing the fuse to go unnecessarily, and clamped connections of all kinds cannot be relied upon so confidently as in the case of continuous current.

Alternating current distribution is at a disadvantage in the question of meters. Owing to the impossibility of employing permanent magnets, it is necessary to resort to an electro-magnet in order to ensure the instruments starting with small currents, and this leads to waste of energy. When inductive circuits have to be supplied, additional difficulties are met with in securing accurate measurements.

It is evident that continuous current should, if possible, be distributed to consumers rather than single-phase alternating. If multiphase current be distributed, the case for continuous is somewhat weakened, but the simplicity is not nearly so great, and in this country, at all events, practically nothing in the direction of multi-phase distribution for all purposes has yet been attempted.

It will be well to now glance rapidly at the relative efficiency of the various systems. It may be assumed that practically the same distributing network will be employed in a large town, whatever the system of generation, so what has actually to be compared is the efficiency of the feeders.

With low pressure generation, the only loss is that due to the resistance of the conductors. This loss varies with the load, and when the load is light is practically negligible; for an ordinary lighting load, therefore, the system is highly efficient for the greater part of the twenty-four hours, and is working at its lowest efficiency at the time of heavy load. The loss thus lasts only for a short time, but it takes place when the generating plant is fully loaded, and hence necessitates increased capacity, and therefore increased capital expenditure.

If a high pressure system be adopted, there is at once a certain loss at all hours of the day, owing to the waste in the transformers. This will

vary at full load from 2 or 3 per cent., with alternating, to 8 or 9 per cent., with continuous current; but with lower loads the efficiency of the apparatus rapidly falls off, until with alternating current generation, unless the transformers can be switched out, the loss is most excessive. In addition to the loss in the transformers, there is, of course, that due to the resistance of the mains, but this is usually small. This last, of course, varies in the same manner as in the case of low pressure generation, but the loss in the transformers is the reverse, that is to say, the percentage loss is a minimum at full load and heaviest at light loads. Hence, with an ordinary lighting system, the waste is considerable. Although, through the efficiency being highest at full load, the capital cost of the generating plant is kept down, there has to be set against this the fact that transformers having an aggregate capacity equal to the maximum rate of output have to be provided. There is thus on the one side the cost of the low pressure mains, plus a certain increase of capacity of the generating plant, and on the other the cost of much smaller mains, but having more costly insulation, plus the cost of the transforming plant, together with its switching gear, sub-station buildings, and attendants.

Up to a radius of a mile from the generating station, the loss of pressure in the low tension feeders can economically be kept down to 10 per cent. at full load, if generating at a pressure of from 400 to 500 volts, and experience shows that up to this distance low pressure is by far the most economical and convenient.

This is, however, by no means the limit of low pressure, a fall of potential double that named and even more being frequently allowed, and a radius of 1½ miles and more being served.

If there be too much demand at a radius of 1½ miles or upwards, it becomes advisable to adopt a high pressure system if it be required to supply from a single station. Whether a high pressure or an extra high pressure system be required will be determined by the extent of the area.

General considerations show that essentially a low pressure system is the best, if the district be suited for it. It is the simplest, safest, most reliable, and most economical. There are, however, many cases in which it is quite inadmissible, and there is no choice but to resort to high pressure, which is then in the nature of a necessary evil, but an evil it certainly is, as compared with low pressure.

The considerations which govern the choice of system will be dealt with in the next chapter.

Assuming that a high pressure system is unavoidable, it will be necessary to compare the advantages of the various systems so far as relates to economy of copper in the feeders; they have already been examined as to their general merits.

The choice lies between continuous current, and alternating single-phase, two-phase, or three-phase. In comparing these, it is important to define clearly the basis of comparison. For low pressures this may properly be the effective pressure, but for high pressures it should be the maximum pressure, since it is this which is usually considered to determine the breakdown point of the dielectric surrounding the conductors, though evidence on this point is not over plentiful.

Inasmuch as we are here concerned only with high pressures, continuous current having already been shown to possess overwhelming advantages over alternating for low pressure feeders, it is obvious that we have to make the comparison on the maximum pressure.

Here another consideration enters into the problem. The stress on the insulation of the conductors for a given difference of potential between them will depend upon whether any portion of the circuit, and, if any, which, is connected to earth. Thus, in a continuous current feeder operating at 2000 volts, the stress on the insulation to earth will only be 1000 volts, if both conductors are equally insulated, but if one be connected to earth, the stress on the other immediately rises to 2000 volts.

Various considerations point to the desirability of working at maximum stress at all times rather than running the risk of an excess pressure suddenly being put on the insulation, and hence it is usual to run with one pole earthed with high pressure continuous and single-phase alternating currents. With two-phase working, it is the practice to earth the middle conductor, while with three-phase the neutral point is usually connected to earth, thus reducing the stress on the insulation below what it would be if one of the conductors were at earth potential. This can, of course, only be done with star winding.

Inasmuch as practice varies with regard to earthing, and as the earthing cannot be applied in exactly the same manner to all systems, it will be most convenient to compare them on the assumption that all conductors are equally well insulated.

On this basis the proportionate amount of copper required by the various systems, taking continuous current as the basis of comparison, is as follows :—

System of Transmission.	Relative Weight of Copper in Mains.
Continuous current, ...	1
Three-phase, ...	$1\frac{1}{2}$
Two-phase, ...	2
Single-phase, ...	2

Clearly, then, on the basis of copper alone, continuous current is by far

the most economical, and next to that comes three-phase, while two-phase and single-phase are on the same footing as one another, but are both uneconomical.

The cost of insulation for continuous current will also be the least, since the copper is of the smallest section, and concentric mains can be employed; but the relative economy of three-phase will be somewhat diminished, as compared with two-phase or single-phase, since a three-core cable is more expensive to make than a concentric.

As has already been pointed out, however, there are important differences between these various kinds of currents, and it is impossible to ignore these considerations. For pressures up to which continuous current can be used, it should certainly be adopted, but this limit is reached, probably, at 1500 volts, almost certainly at 2000 volts, for ordinary working.

If the whole supply is to be converted into continuous current for distribution, as is in the Author's opinion the best course, then three-phase is certainly to be preferred to two-phase or single-phase. If, on the contrary, it be determined to distribute alternating current, then the difficulties of balancing the lighting circuits with three-phase current are probably so great as to more than counterbalance the advantage of saving in copper, and two-phase is then to be preferred. In such a case, the lighting supply would be single-phase, a portion being supplied from one of the two phases and a portion from the other, while motors would be supplied from both. Incidentally, the two-phase system admits of old single-phase mains being employed in two-phase work, and, in the case of change of system, this one consideration is usually conclusive in favour of two-phase. Single-phase transmission is undoubtedly the least desirable of any; its only merit being simplicity.

CHAPTER VI.

THE CHOICE OF A SITE FOR THE GENERATING STATION, AND OF THE SYSTEM OF SUPPLY.

THE position of the site and the system of supply to be adopted are so closely connected that it is most difficult to consider them independently. It is usually impossible to choose the site for a generating station with reference to engineering considerations alone; in practice there are most frequently several sites only available, and the balance has to be struck between the advantages and disadvantages of each. It will be well, however, to consider the features which an ideal site should possess, and it can then be seen how nearly an actual site approximates to the ideal.

Similarly, it will be convenient to study what is the best system for a given area on the assumption that the site can be obtained where wanted. The result in practice will be a compromise; but it may be remarked, that wherever the site is obtained it will be possible to select an efficient system, though it may not be ideally perfect.

It is necessary first to distinguish between the two cases of districts embracing large and small areas respectively to be supplied.

For a small area, *i.e.*, one in which the supply can be given at low pressure from a single generating station (see above, p. 30), every effort should be made to secure a site as near as possible to what may be called the centre of gravity of the demand; that is to say, the point in which there is the greatest demand for energy within unit radius. If the area be one which cannot be served from a single station at low pressure, it must first be determined whether one or several generating stations are to be adopted; if several, they must be placed in the densest portions of the area; if a single station working at high pressure, the element of position of densest demand will be of less, but still not of negligible importance.

Whatever the system of generation, the following points are material:—

(1) Accessibility.

(*a*) For the delivery of coal and removal of cinders.

(*b*) For the delivery of heavy machinery and of stores of all kinds.

(c) For connection to mains.

(d) For officials and workmen.

(2) Proximity to water.

(a) For condensing.

(b) For boiler feeding.

(3) Stability of foundations.

(4) Isolation, to secure freedom from causing nuisance by noise, vibration, smoke, dirt, fuel, carting, etc.

(5) Facility for extension.

(1) *Accessibility.*—(a) Seeing that coal is the usual source of the energy delivered by central stations in this country, it is of primary importance that the price paid should be the lowest possible. For a given town, this will depend chiefly upon the cost of carriage to the works. A surprising difference is often caused by a distance of only a few miles. The most advantageous position is adjoining a railway from which a siding can be taken into the works, for by this means a much larger selection of collieries can be obtained than in any other way. It might be thought that a canal or other waterway would be preferable; but this is not so, for although water carriage is usually cheaper than rail, the number of collieries having rail, but not water, connections, enormously preponderates, and hence the lower rates are discounted by restricted competition. Again, it is usually easier, and therefore cheaper, to unload railway trucks than barges. A further very weighty argument in favour of railway carriage is that there is much less liability to interruption of service—a canal being subject to freezing in winter, and shortness of water in summer in times of drought; while rivers, though less liable to interruption from frost, may become unnavigable in times of flood. If possible, both rail and water carriage should be available.

The removal of cinders may be a most costly item, and it is important to see that the projected site affords conveniences for getting rid of them.

(b) The machinery likely to be used in most central stations in the near future is very bulky and massive, and its first cost will be considerably augmented if ready means of transport do not exist. The same considerations as to carriage of coal do not apply here with equal force. The size of an article that may come by rail is limited by the height of bridges and tunnels, and in some cases it may be much easier to bring the plant by water, or even by road; moreover, since the place where the machinery is made may be situated at a very long distance, the saving effected by the low rates for water carriage may be great. For the delivery of stores it is important that there should be good facilities; the same conditions here obtain as in the case of coal.

(c) Care should be taken to see that there is a clear run, with ample space for the laying of mains. The number of conductors leaving the

generating station grows very rapidly, and the space available underground may very soon be used up. It is preferable that there should be several roads leading to the works, so as to avoid the mains being concentrated into a narrow neck; the liability to complete interruption of supply is also by this means diminished.

(*d*) It is advisable, if possible, to arrange for the works to be in a neighbourhood where the workmen can readily obtain accommodation, or near a railway or tramway giving cheap access to such neighbourhood. Labour is a heavy item of cost, and it is advisable to have as free a hand as possible in making selection of men.

(2) *Proximity to Water.*—(*a*) The necessity for a cheap and abundant water supply is paramount. No great measure of success can be looked for unless it be possible to employ condensing engines, and although this may be done with a limited amount of water by the employment of water-cooling apparatus, such arrangements are costly to instal and to maintain, occupy valuable space, and are liable to cause considerable nuisance from escaping steam. A site adjoining a river or canal is therefore to be sought.

(*b*) The provision of water for boiler feeding is most important. Here abundance is not of so much importance as quality, for while almost any kind of water can be used advantageously for condensing purposes, the water for the boilers must be as free as possible from hardness and from corrosive qualities. Seeing the effect that the water has upon the life of the boilers, it may often be preferable to take water from the general town supply, even when other water is available; for it is possible to economise the amount used very readily, and that without the erection of expensive works or causing a nuisance.

(3) *Stability of Foundations.*—The nature of the foundation should be carefully investigated before deciding upon a site, for the weights dealt with are great both in the machinery and the buildings. An indifferent foundation will add largely to the cost of erection, and may give rise to much trouble, expense, and even danger when the station is at work. In certain parts of the country it is also necessary to guard against there being any mining rights beneath the surface.

(4) Much trouble is often experienced from complaints as to alleged nuisances caused by generating stations. Most of the forms of nuisance can be guarded against, but it is sometimes costly to carry out the preparations calculated to prevent them, and in all cases such precautions fetter the engineer in his choice of plant. Further than this, vexatious complaints are often made which are most harassing, and while they have little basis in fact, yet have sufficient ground to prevent their being wholly ignored with safety. Again, under certain conditions, a nuisance such as that arising from black smoke cannot be wholly avoided. For these reasons it is desirable, if practicable, to choose a spot remote from valuable property.

(5) *Facility for Extension.*—It is common experience that central stations grow to a far greater extent than is anticipated at their inception, and the original site chosen is often too small; moreover, it is not advisable to burden a new undertaking with too heavy a charge for capital at the start. Under these circumstances the best course to be pursued is to obtain a site in such a position that additional land can readily be purchased adjoining it; but if there be the slightest doubt about this, it is wisest to purchase an amount of land that will be amply sufficient for any possible future requirements, since, in any case, it can be re-sold and, even if at a loss, such loss will be trifling, as compared with the inconvenience and expense caused by having to purchase additional space in some other locality.

It is needless to point out that the capital expended on the site involves a fixed annual charge for interest, and, in the case of municipalities, for sinking fund; since these fixed charges are such that they cannot be reduced by good management, it is of vital importance to keep them as low as possible.

In calculating the amount of land required, it must be remembered that the nature of the operations to be carried on is such that every precaution against their interruption must be taken. This points to the provision of adequate space for storing a supply of coal (the larger the better in reason), for the storage of water, and, in a large station, for repairing shops.

Now, if the area is not more than two miles square, and a site can be obtained reasonably near the centre, the system should certainly be a low pressure, continuous current, one distributed on a multiple wire network. The pressure across the outside conductors should be as high as is consistent with safety, with the fulfilment of the Board of Trade regulations, and with economy to the consumers as regards lamps and apparatus.

Probably, taking all things into consideration, 440 volts is as good a pressure as can be adopted. This gives a good margin for drop of pressure in the feeders without getting too close to the limit of low pressure, and the generators will be suitable for supplying current for traction purposes at the standard pressure of 500 volts, if required.

If this figure be adopted, the pressure on the consumers' terminals will either be 110 or 220 volts, according as the five- or three-wire system is adopted. Improvements in high voltage lamps have been so great that in the majority of districts there need be no hesitation in declaring the higher pressure, and adopting a three-wire network. It cannot be denied, however, that the five-wire system, by allowing the pressure to be halved, possesses important advantages in streets where there are a number of small shops in which two small arc lamps would be readily taken up, while four would be prohibitive in price, and for the owners of which the first cost of the lamps is a material consideration. The

lower pressure also is undoubtedly advantageous where very small motors are required.

Manchester is the only place in the United Kingdom using the five-wire system; hence few English engineers have had experience of it. There can be no doubt that its use requires a considerable amount of care in the balancing of consumers, but, provided that this point be attended to, it is entirely successful. The Author is strongly of opinion that, had it not been for the introduction of the 200 volt lamp, this system would have been adopted in all cases of low pressure distribution.

The pressure of 110 volts and its multiples appears to be the most suitable for arc lamps, and hence it is best adapted to the requirements of the consumer.

If the area is materially larger than that named, we are at once confronted with the question as to whether it should be split up into several sections, each having its own low pressure station, or whether a single high pressure station should be erected. The answer will be determined by local conditions; a hard and fast rule cannot be laid down.

The arguments for and against a single generating station working at high pressure, as opposed to several working at low pressure, are many; the point is one that has been much debated, and there still remains considerable difference of opinion. In this, as in so many other cases, the fact of the matter is that it is impossible to arrive at a decision without a knowledge of local conditions.

If the district be one with a very dense demand throughout, or if it consist of several dense areas joined by streets wherein there will be practically no demand, then, if sites with suitable conveniences can be obtained, it may well be that several stations will best meet the requirements. On the other hand, if the demand in the area be not particularly, or specially, dense in any one part, or if there be difficulties in the way of procuring sites, such, for instance, as expensive carriage for coal, absence of condensing water, likelihood of causing a nuisance, etc., then a single station is certainly to be preferred.

For a large area, however, there is much to be said for a single station on its merits apart from the above considerations. It seems almost certain that economy in management must result from concentration; the works being on a larger scale, the size of generator can be augmented with the result of some gain in efficiency, a large gain in cost of attendance, and probably some advantage as to reliability and cost of repairs. The large scale of operations enables a larger outlay on labour-saving appliances, especially coal-handling plant, to be profitably made with the result of cheaper production. Again, the use of high pressure enables the station to be placed outside the district of principal supply; this is of the utmost

advantage, especially in a residential district, as it certainly gives favourable opportunities for economy in the cost of land, fuel, and water, and for minimising complaints as to nuisance. Another important advantage of a single station is, that the load on it is likely to be more uniform than on one of several stations, owing to districts of varying character being supplied from it, as the time of maximum demand in one will not coincide with that in others, and the load will thus be maintained at a high value for a longer time.

It may be urged against these advantages that sites must be secured for sub-stations, and that attendance in these will be necessary, while the high tension mains are costly. It seems the most natural course, however, to regard these sub-stations and their expenses, together with the mains, as feeders, and their cost must then be set against the cost of the low tension feeders that would be required with the other system ; this, then, leaves the economies effected by the large station undisturbed.

The principle of concentration may, however, be carried too far, as in the case of proposals which have been made for the supply of districts of hundreds of square miles in extent. Such a station will have a load differing but slightly, if at all, from that of a single large town, and its fuel consumption will be very similar, though the cost of coal per ton may be diminished if the proprietors of the station are likewise owners of immediately adjacent collieries. This saving, whatever it may be, is practically all that can be set against the enormous cost of the high tension mains and the increased cost of plant, owing to the high pressure necessary—for such a station could hardly work at less than 20,000 volts. The only justification for the establishment of such a station would be the availability of abundant, reliable, and very cheap water power.

After a careful study of the question, the general rules that the Author would lay down are :—(1) For any area, whatever the character of the demand, in which the greatest radial distance from the generating station to any consumer does not exceed 1 mile, low pressure continuous current should be generated, and distributed on the three-wire system, with a pressure of 440 volts across the outers. (2) If the radial distance from the station does not exceed $1\frac{1}{2}$ miles, but the bulk of the demand is within a mile, the same system should be employed. (3) If the radial distance from the centre of the area exceeds $1\frac{1}{2}$ miles, but is not more than 2 miles, and the whole area is dense as regards demand, or even if the radius be only $1\frac{1}{2}$ miles, but the density is very great throughout, then two or three stations employing the same system will probably give the best results. (4) If, on the contrary, the area be very sparsely populated, and the radius from the centre exceeds $1\frac{1}{2}$ miles, or in exceptional cases, 1 mile, and if there be no likelihood of having to supply energy for motive power or arc lighting, then a high pressure single-phase alternating system with transformers

in each house, or for each group of houses, is probably the best. These conditions are likely to arise only in a village or nest of villages, and the system cannot be recommended for any place with any pretensions to being called a town. (5) If the radius from the centre exceed 2 miles, it is very doubtful whether the use of a number of low pressure stations can be justified, though it is possible that in a few exceptional cases it might be. Under ordinary circumstances, a high pressure station should certainly be put down. If the radius from the generating station does not exceed 3 miles, the safest, simplest, and most convenient system will probably be one in which high pressure continuous current is generated at a pressure of 1500 volts, and transformed in sub-stations placed about a mile apart, into continuous current at a pressure of 440 volts, distributed on the three-wire system. (6) Lastly, if the radius from the generating station exceed 3 miles, there can be little doubt that the best system consists in generating three-phase current at a pressure depending on the distance, and transforming this, in sub-stations placed about a mile apart, into continuous current at a pressure of 440 volts, distributing it on the three-wire system as before.

These rules are merely general, and must be modified to suit individual cases; they are also far from final. They may, and very probably will, be modified greatly as time goes on. There is considerable likelihood that two-phase and three-phase distribution may attain such development as to become suitable for purposes of general supply, in which case the distribution would be effected by multi-phase instead of by continuous current. Again, such improvements may be effected in single-phase motors, that this class of current may become suitable for distribution, though this seems somewhat doubtful. Satisfactory lamps may yet be made for pressures of 300 volts, so that the field of low pressure generation may be considerably extended, but this is probably the extreme limit, for this implies a pressure of 600 volts across the outer conductors, and such a pressure undoubtedly cannot be exceeded without danger to life.

The distances given are, of course, approximate only. Thus the distance apart of the sub-stations is necessarily dependent upon the nature of the district. If very sparsely covered, they may be further apart; if extra dense, they may be a little closer together.

If the supply of energy for traction be included in the scheme, the case for a single station working in conjunction with a number of sub-stations is greatly strengthened, for a number of supply points is certainly the simplest and easiest solution of the difficulties as to electrolysis of adjacent conductors in the soil when earth returns are used.

At the present time, also, traction is a strong argument for distributing continuous current, though it is quite possible that three-phase motors may be employed in the future.

It is often objected to low pressure continuous current that, however well it may be adapted to a district in which the demand has become established, high pressure single-phase alternating is much better adapted for pioneering work. In the Author's opinion, this is a great mistake. When a new district is opened up, and mains are laid, it would seem to be the wisest course to at once lay the permanent distributing mains. The cost of opening the ground—a large part of the whole cost—is practically no more, and the only extra cost is for the additional copper. The section of copper being out of all proportion to the demand during the pioneering period, consumers whose premises are at a great distance can be supplied at low pressure without difficulty. When the demand grows, and the mains become loaded up, feeders of a type suitable for the permanent work can be put down; these will, of course, be either low pressure, or high pressure with attached substations, as the case may be. By adopting this course nothing has to be done over again or superseded.

The advisability of putting down a battery or batteries is one to which close attention must be given. Briefly, the advantages of batteries are that they enable the load on the generating station to be equalised by providing work for the plant when the demand is light, the cells being then charged, and by assisting the plant by discharging when the load is heavy. They may also be employed to run the whole load when the demand is very small, and under certain circumstances they may act as a reserve of energy.

There is a weak side to batteries, however: they are exceedingly expensive in first cost and upkeep, and their efficiency is low.

In a small station a battery is of great advantage, as it may be used to run the whole load after a certain hour at night, and a portion of the day load, thus saving a good deal in attendance, and improving the efficiency of the generating plant.

If there be also a demand for traction for a moderate number of cars, a battery will further be of the utmost value in steadying the load, which, without it, would fluctuate greatly.

In very small stations a sufficiently large battery may be put in to enable the whole load to be run for a short time, and thus it will act as a standby.

In a large station the field of usefulness is different. In the first place, it cannot in any sense be looked upon as a standby; the cost of a sufficiently large battery for this purpose would be altogether prohibitive.

Again, its use as a steadying device for a traction load is of little advantage, since, in a station operating several hundred cars, the fluctuations of load are comparatively small.

Whether the battery can take the load after a certain hour at night depends on the district; in most stations it probably would, in others the size required would probably be too great. Even when a battery can be used

for this purpose, the saving in a large station is not nearly so great in proportion as in a small, because men must be on duty all night to watch the boilers, and coal must be burnt to keep them and the steam-pipes hot, it being impracticable to allow a large system to cool down at night, and hence the extra cost of running a generator is not great.

In high pressure systems, however, the saving may be as great as in a small station if batteries be placed in the sub-stations, for they will enable the high pressure plant in them to be shut down, and many of the high pressure mains to be switched off, thus saving attendance at the sub-stations, and waste in the high pressure mains and transformers.

Whatever the size of the station, batteries are of use in steadying the load, and their value for this purpose is very great.

It may be anticipated, with some confidence, that batteries will be improved and cheapened in the future. If this be done, then the ideal conditions will be attained by the provision of a battery large enough to keep the generating plant working all night at charging it, the discharge being taken from the battery during the day and evening. This ideal, however, is at present a long way from being realised.

CHAPTER VII.

ARCHITECTURAL FEATURES OF GENERATING AND TRANSFORMING STATIONS.

A GENERATING station consists essentially of an engine house, a boiler house with chimneys, and offices. To these must be added other buildings, according to the size of the works. Thus, in a large station, there will be coal stores, water reservoirs, pump houses, repairing shops, testing rooms, stores, dwellings, etc.

The ideal arrangement is to have offices and stores at the entrance, with careful provision to ensure that all persons and goods shall only be able to enter under close surveillance. Behind the offices should be the engine house and boiler house, parallel to one another, so as to secure the minimum length of steam pipe, and therefore the minimum waste by radiation of heat.

The buildings generally should be of plain exterior, so as to keep down unproductive capital cost as far as possible; but in the interior considerable liberality may, with advantage, be shown, as increased expenditure will be more than compensated for by diminished running expenses. Thus a glazed brick wall, though costly, can be readily kept clean, requires no beautifying, and can give off no dust; hence considerable expense is saved annually.

It is of vital importance that the whole of the buildings should be as fire-resisting as it is possible to make them. The damage effected by fire in a generating station is altogether out of proportion to the value of the plant destroyed. It is not the loss of the money represented by the cost of the plant that is to be dreaded, for this can be readily provided against at a fairly moderate rate by insurance as in ordinary risks, but it is the loss through interruption in supply, not only of revenue, but, what is far worse, of credit or prestige, that is so damaging. The harm that may be done by a bad fire is incalculable, and may readily be not less than the complete ruin of the undertaking.

The engine house should be so disposed that the whole of its area can be readily controlled by travelling cranes, and provision must be made for carrying the gantries of these. It must be constructed so that there can be obtained a clear view from the spot where the switchboard is to be fixed over the whole of the space.

The height of the building will be determined by the character of the engines and dynamos employed. It must be such as to enable the most bulky parts to be readily lifted into position, and travelled to any point. Care must be taken to see that the largest part of any engine or machine can be brought to its place from the entrance.

It is highly desirable to excavate the whole space included within the walls to a depth of ten or twelve feet, so as to admit of roomy passages among the foundations of the generators. The steam pipes can then be placed beneath the floor, and by this means the difficulty of keeping joints tight will be greatly diminished, since they will be kept at a much more uniform temperature than if fixed overhead in the engine room. Again, this arrangement tends greatly to keep the space clear for using the travellers, and for viewing the working of the plant from the switchboard. The underground passages also enable the conductors to be dealt with easily, and they give facilities in many ways for keeping the appearance of the station good.

So far as the ideal from a fire-resisting point of view is concerned, brick, stone, and concrete are the best materials of which to construct the building, but from many other aspects the use of a steel framework, filled in with brickwork, has much to recommend it. The chief advantages of such a system are that it can be constructed rapidly, and this is usually of importance; the frame and roof can be constructed and the walls filled in afterwards while the plant is being erected; the attachments for supporting the crane gantries and other plant can be made with great ease; and, lastly, the construction is, on the whole, cheaper, and less excavation is required for the foundations. In order to make such a building secure in the event of fire, the steel should be encased as far as possible in brick or concrete. Cast-iron softens in a fire much less readily than steel, but is apt to crack if water is brought into contact with it while hot. It should be used where practicable, but the bulk of the work will be most conveniently carried out in steel.

The roof is usually the most vulnerable part of the structure of a central station, and very little attention has been paid to this point. An exceedingly good roof is illustrated in fig. 9. It is of the 'weaving shed' or 'saw-tooth' type, which admits of most excellent lighting.

Referring to the general outline, it will be seen that it consists of a number of ridges parallel to one another, each having one side steeply inclined, and the other making a low angle with the horizontal. The steep side is glazed, and is made to face north, if possible, while the other is slated.

The method of construction will be clear from the details shown. Between two adjacent ridges runs a cast iron trough, which is carried in any convenient way. In the case of mills, a column is usually placed beneath

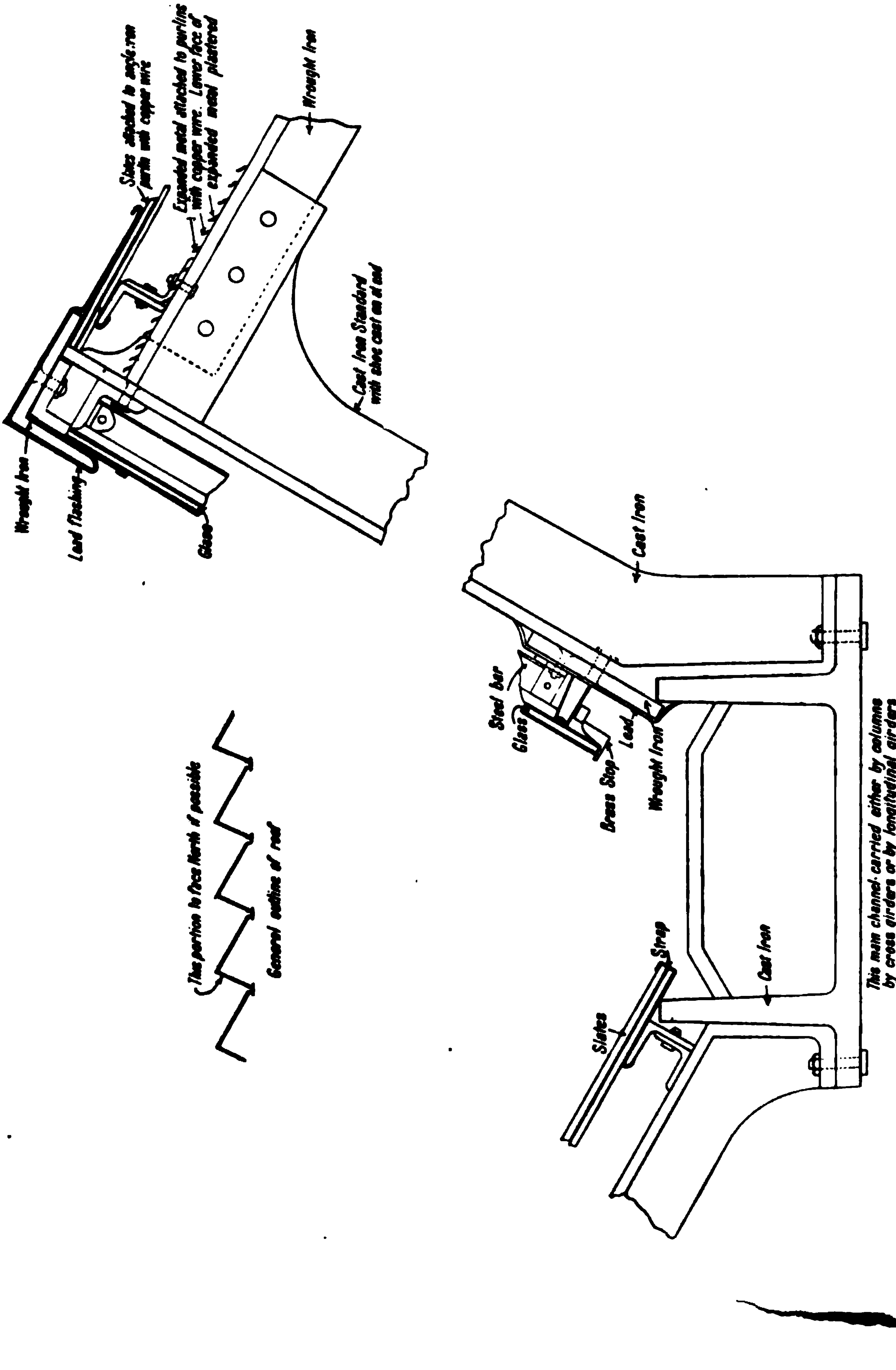

Slates attached to angle iron purlin with copper wire
Expanded metal attached to purlins with copper wire. Lower face of expanded metal plastered
Wrought Iron
Cast Iron Standard with shoe cast on at end
Wrought Iron
Lead flashing
Glass
This portion to face North if possible
General outline of roof
Cast Iron
Steel bar
Glass
Brass Stop
Lead
Wrought Iron
Slates
Strap
Cast Iron
This main channel carried either by columns by cross girders or by longitudinal girders running the whole length

FIG. 9.

every other trough, the alternate troughs being carried by light girders thrown across from column to column; but for central station work, the columns are nearly always inadmissible, and the troughs can then be carried on strong girders either running beneath the troughs in the direction of their length and supporting them at every point, or else at right angles to them, as when columns are employed.

The steep side of a ridge is of cast iron, bolted to the trough at the bottom, and having a shoe cast at its upper end. Into this shoe drops a wrought iron T, having its lower end bolted to the next trough.

Wrought iron purlins, running parallel to the troughs, tie the frames together, and form the support for the glazing, which is of one of the patent forms requiring no putty, and also for the slates which are secured to them by copper wire.

Expanded metal is fixed beneath the slates, and serves as a key for the plaster.

Lead flashing is employed to make the roof water-tight.

The window frames should be of cast iron throughout, and doors should be of wrought iron; they should slide in all cases, and when small, it will be found convenient to arrange them to slide upwards. When this is done a safety catch should be provided to avoid all risk of the door acting as a guillotine. Every particle of wood that can by any possibility be avoided should be dispensed with.

The interior should be lined from floor to roof with white or cream glazed bricks, a high dado of dark glazed bricks being provided for appearance sake.

Provision should be made for an ample amount of light; there cannot be too much, for the better the plant can be seen, the better the chance of its being maintained in a high state of efficiency.

The ventilation of the engine room should receive most careful attention. Experience shows that the most efficient ventilation is secured by a combination of the vacuum and plenum systems; that is to say, the air is both withdrawn from near the roof by means of exhausters, and fresh air is forced in near the floor by fans. The cool air should be directed towards the generators, care being taken, however, not to thereby deposit dust upon them.

It is advisable to have a number of fans of moderate size rather than one or two very large ones. They should, of course, be driven electrically.

The importance of good ventilation is considerable, for, besides making the atmosphere more wholesome and comfortable for the staff, it increases the efficiency of the whole of the electrical plant by diminishing its temperature.

No provision need be made for heating the buildings, since this is more than effected by the steam pipes and engines, even when thoroughly well lagged.

It is somewhat difficult to decide on the best floor for the engine house. It should be such that it can be easily cleaned, that it will not give rise to dust as it wears, that it will not absorb oil, that it will not break or chip, and it should be non-slipping. On the whole, adamantine tiles, with unglazed surface, of substantial thickness, and laid in cement, appear the most suitable. Guards of some kind should be placed round wheel pits and all openings, so that when the floor is washed the water may not get into them, and the floor should slope towards definite points, at which drains should be placed to carry off the water. Great care should be taken to thoroughly drain all wheel pits and the whole of the space beneath the floor. Wheel pits should be lined with glazed brick, so that they may be kept perfectly clean, care being taken to tie the brickwork well into the concrete.

All foundations for generators should be of ample depth and solidity to avoid vibration, and, for the same reason, they should not abut on the walls. In the neighbourhood of high-class property, special precautions against vibration must be taken.

The boiler house should be at a lower level than the engine house, and as already stated, should be parallel to it. Like the engine house, it should be of fire-resisting construction, but, unlike it, should not be too well lighted, as in firing it is preferable for the stokers to be in semi-darkness, as they can then more easily see the fires. Where good illumination is required, as on the gauges and gauge glasses, it can readily be provided for by means of lamps.

The building should be such that the boilers can be symmetrically grouped about the chimney or chimneys, and that they can be attended to by the smallest possible number of firemen.

In designing the building, it must be borne in mind that the rate of depreciation of boilers is much higher than that of buildings, and that therefore the boilers will, in course of time, have to be removed and replaced by others, and sufficient space must be allowed for this. If tubular boilers be employed, space must be left for the ready withdrawal of any tube.

It is very advantageous to line the interior of the boiler house with glazed brick, for the sake of cleanliness and the avoidance of frequent white-washing. The floor being subject to having heavy rakes thrown upon it, and to rough treatment generally, tiles are unsuitable. Blue bricks on edge make as satisfactory a floor as can be devised, as they are strong, not slippery, and have a surface which admits of a shovel being freely used.

The roof should be of the same character as that of the engine house, unless it be formed by a tank. If this latter course be adopted, provision must be made against condensation on its surface. Many expedients may be resorted to for the purpose, but perhaps the best and simplest is efficient ventilation.

It must be remembered that large volumes of air are required to be drawn through the boiler furnaces, and ingress for this into the boiler house must be allowed for. In the interests of the firemen, the inlets should be of large area, so as to avoid violent draughts.

The chimney should be constructed of brick, as, although wrought iron shafts are cheaper in first cost, and can be more rapidly erected, the expense incurred for their maintenance is very heavy. It is greatly to be preferred that there should be at least two chimneys, so that arrangements may be readily made for cleaning the soot away from the bases. Provision should be made, by means of arches, for the entrance of all flues that may by any possibility be required, so that there may never be any necessity at any time to cut into the main fabric of the chimney. Some information on the design of chimneys will be found in Chapter X.

Doors should be provided in the main flues at suitable points, to allow of their being readily cleaned. They should be so constructed, as also should the chimney, that there may be no danger of water gaining access to them.

A small repairing shop, with a few tools, is most useful, and this should adjoin the engine house, but should be distinct from it, in order to avoid dirt, and the danger of iron filings and small tools being drawn into the machines.

The offices required will vary greatly with the size of station, and will depend upon whether it is the only generating station or is one of several. There will, in all cases, be required an office for the engineer on duty, which should communicate directly with the switchboard. A store, large enough to contain a supply of engine room stores and small spare parts, is also essential, and an office for inquiries and one for a few clerks.

The general arrangement of the works should be such as to admit of easy delivery of goods and plant in the various parts in which they are required. Alternative avenues for coal should be provided. Thus, if it be brought normally by rail or canal, there should be facilities for taking delivery by cart, and the arrangements, if possible, should be such that the carts can follow one another in a procession, so that one need not wait for its predecessor to be unloaded before it can enter the works.

The actual design of the station will necessarily depend much upon both the size and shape of the site available. If, by reason of high cost or scarcity of land, it is necessary to greatly economise space, the buildings will have to be cramped, and the clearances and gangways cut fine; but where the cost of land is moderate, ample space should be provided. Plenty of room tends to convenience, saving of time, and general efficiency and cleanliness.

In America it is very common to have a building of several storeys, the coal occupying the top, the boilers being next, and the generators below.

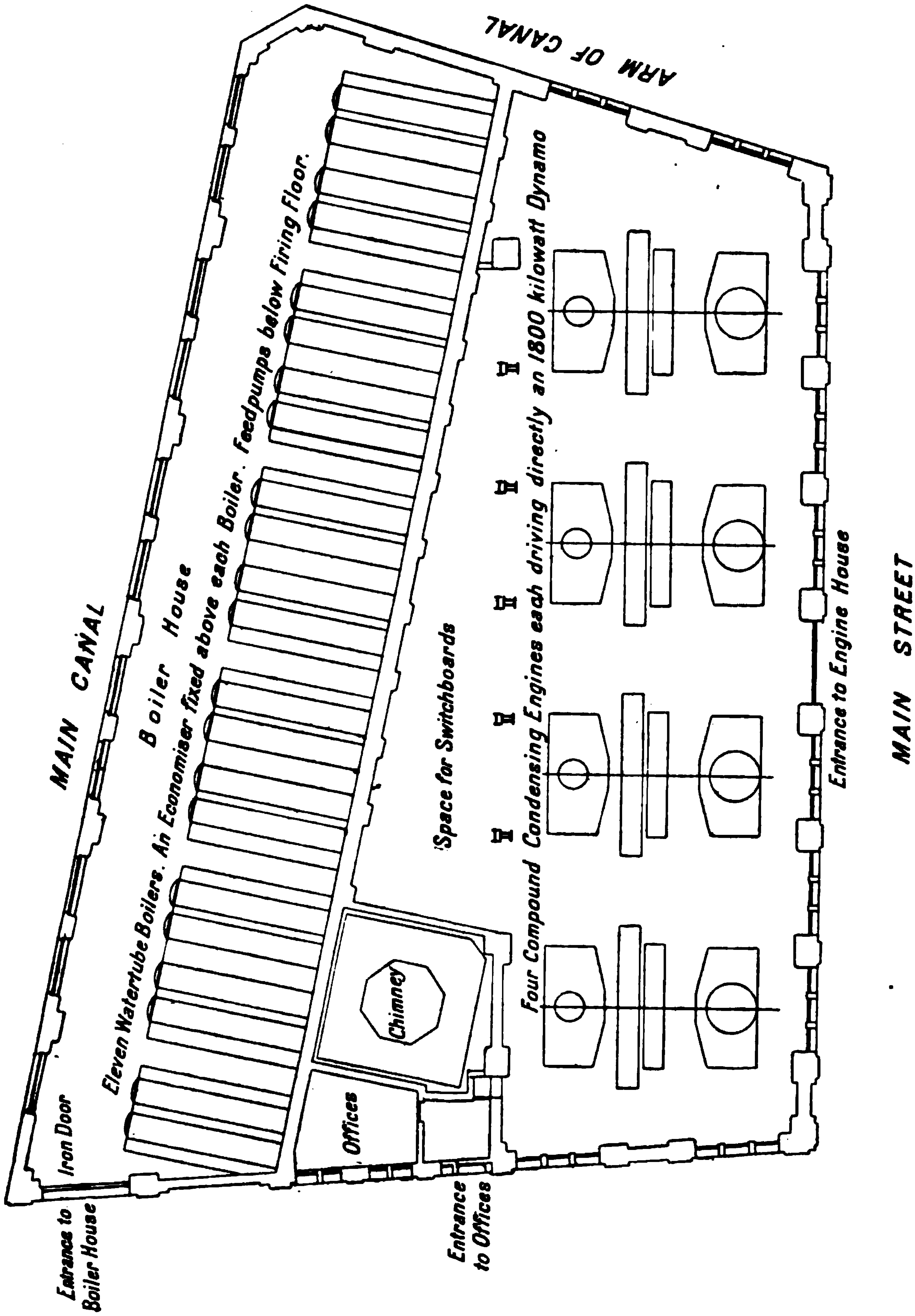
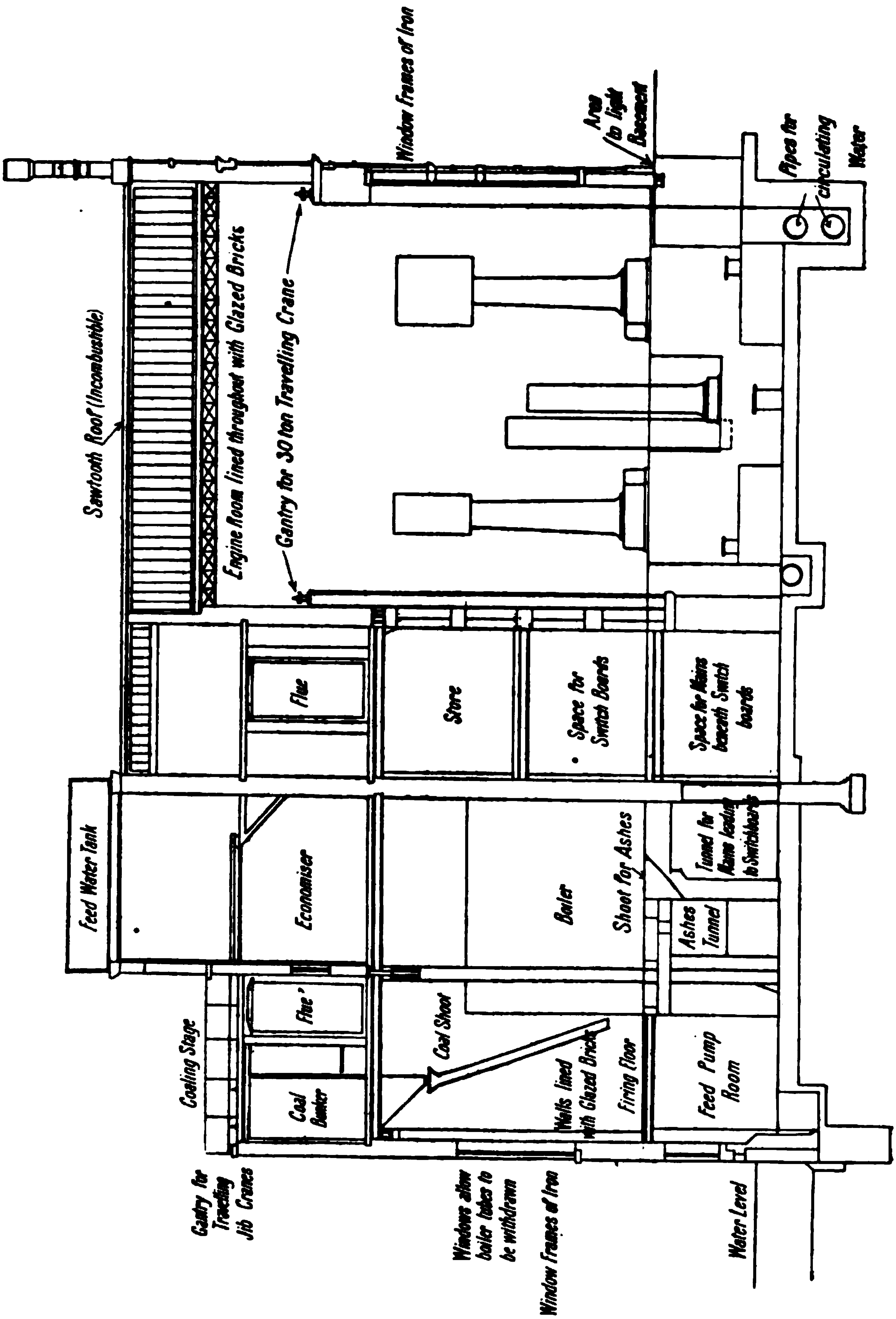

MAIN CANAL
ARM OF CANAL
MAIN STREET
Boiler House
Eleven Watertube Boilers. An Economiser fixed above each Boiler. Feedpumps below Firing Floor.
Space for Switchboards
Four Compound Condensing Engines each driving directly an 1800 kilowatt Dynamo
Chimney
Offices
Iron Door
Entrance to Boiler House
Entrance to Offices
Entrance to Engine House

FIG. 10.



Window Frames of Iron
Area to light Basement
Pipes for circulating Water
Sawtooth Roof (Incombustible)
Engine Room lined throughout with Glazed Bricks
Gantry for 30 ton Travelling Crane
Flue
Store
Space for Switch Boards
Space for Mains beneath Switch boards
Feed Water Tank
Economiser
Boiler
Shoot for Ashes
Tunnel for Mains leading to Switchboards
Ashes Tunnel
Coaling Stage
Flue
Coal Shoot
Coal Bunker
Walls lined with Glazed Bricks
Firing Floor
Feed Pump Room
Gantry for Travelling Jib Cranes
Windows allow boiler tubes to be withdrawn
Window Frames of Iron
Water Level

Fig. 11.

This plan has not met with favour in this country, and could only be justified by exceptional circumstances.

A plan and section of a station designed to accommodate as much plant as possible in the minimum space is shown in plan and section in figs. 10 and 11 respectively. It is the Bloom Street Station of the Manchester Corporation, designed by the Author for containing plant developing 14,000 I.H.P., the total ground space occupied being 1923 square yards, or 7·2 H.P. per yard of floor space, including boilers, generators, and all accessories. The drawings must be taken as diagrammatic only, most of the detail being omitted.

In many towns it will be necessary to contemplate generating stations of very large size, and in these, in all probability, current will be generated at high pressure, so that there will be considerable flexibility as to the location of the site, and it will be possible to obtain ample space.

The general principles already enunciated will hold good with some modifications, but the design will be more elaborate. It will be possible to make provision for many conveniences and refinements that could not be attempted in a station cramped for space.

In a very large station the single generators will be of considerable size, certainly 5000 H.P.; hence the space required in the engine room per indicated horsepower will be much less than in the boiler house, for boilers cannot possibly be obtained of corresponding size. The ratio of the engine room space to the boiler house space will vary greatly with the type of boiler, and the disproportion will be much more if Lancashire boilers be employed than if those of the tubular type be decided upon.

As the Lancashire boiler has many advocates, it may be as well to consider the arrangements necessary for the accommodation of these boilers. Take the case of a generating station having a capacity of 50,000 H.P., and in which steam is raised at a pressure of 160 lbs. per square inch. The largest size of boiler which it will be desirable to employ will be 30 feet long and 8 feet diameter, and of these 112 will be required, whereas there will not be more than from ten to twelve generators. Obviously the principle of having the boiler house parallel with the engine house will not here apply. In this case the best arrangement is to have the boilers arranged in a number of short boiler houses, branching at right angles to the engine house and arranged alongside it. Such a station is shown in plan in fig. 12. There are here four boiler houses, each with its own chimney, arranged side by side, and just occupying the length of the engine house. The arrangement can be criticised in several ways, especially from the standpoint of radiation losses and difficulties with expansion of pipes. It shows clearly the difficulties in the way of applying Lancashire boilers to very large stations.

In a large station very ample coal storage space is essential. This

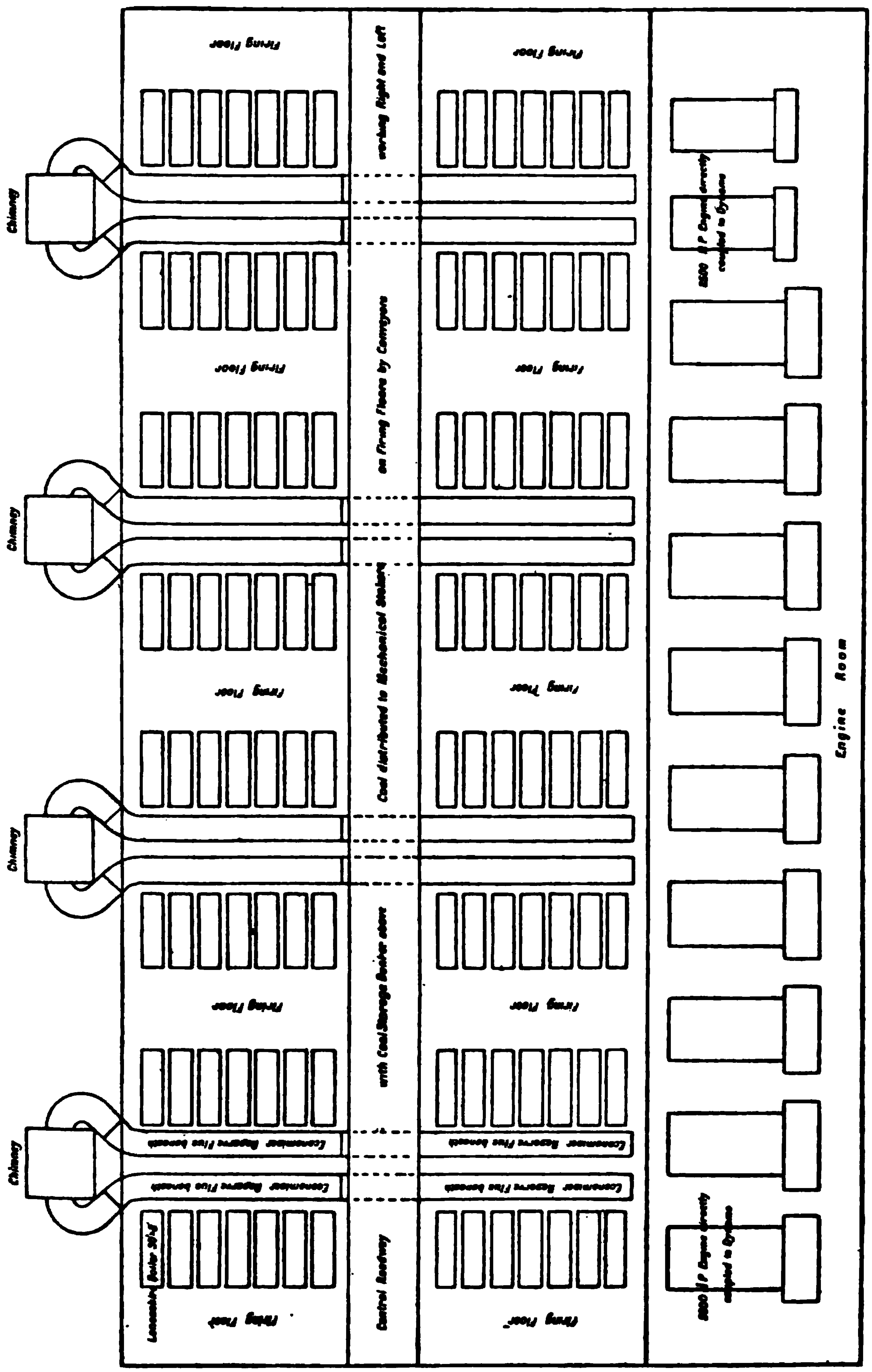


FIG. 12.

is important in a small station, but much more so in a large; for the larger the station, the greater the dislocation of trade and public inconvenience in the event of interruption in supply. A station of the size above named ought to store not less than three months' supply.

Unless the station be on a large river, or by the sea, it will be essential, if the capacity be of the order of 50,000 I.H.P., to provide for the artificial cooling of the water, and cooling towers will be required, supplemented possibly by reservoirs.

In a large station it will be found advisable to have repairing shops of considerable magnitude, especially if the town be one in which large engineering workshops do not exist.

A residence for the engineer in charge of the station will be required, and a few houses for workmen and foremen will also be necessary. It is advisable, in order to avoid rating difficulties, that these should be quite distinct from the works.

The question of transform-

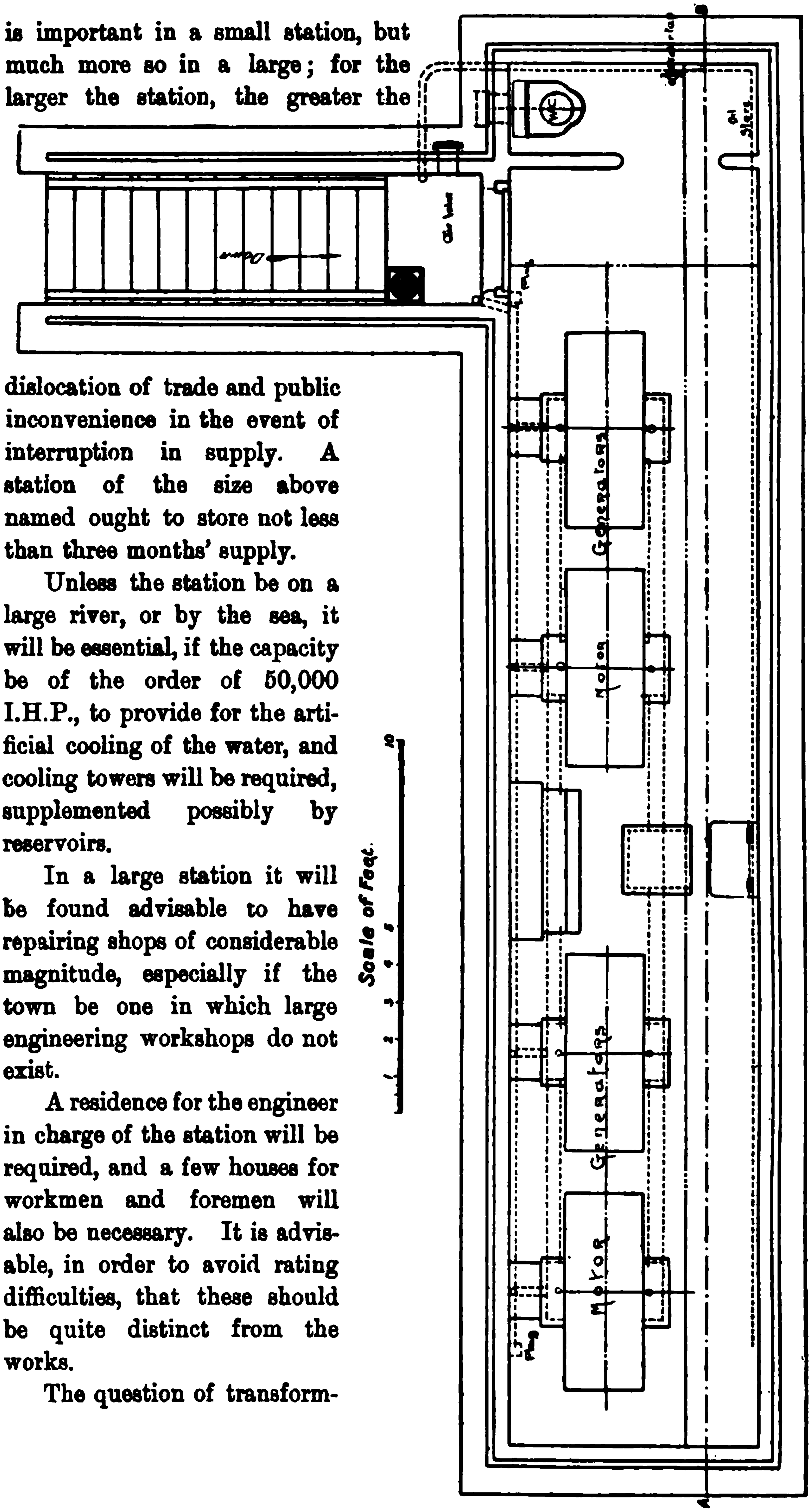
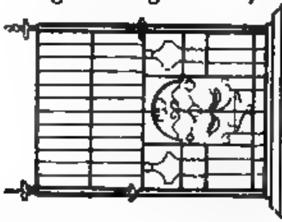


FIG. 13A.

ing stations, though very simple as compared with generating stations,



is yet one which calls for care and consideration.

Transforming stations may be divided into those constructed beneath the surface of the street, and those in which the plant is housed in an ordinary building. The former are usually small, the capacity of the plant fixed in them not exceeding a few hundred kilowatts, while the others may contain plant of three or four thousand kilowatts.

The three chief points in an underground sub-station are water-tightness, non-combustibility, and good ventilation.

The best method of rendering these structures water-tight is to form a lining of brick, preferably glazed, leaving a cavity between the lining and the wall proper, which is filled up completely with bitumen. If preferred, a layer of felt prepared with bitumen may be inserted in place of the bitumen; when this is done no cavity is left.

The roof is best formed of iron or steel girders and concrete, a layer of bitumen or bitumenised felt being placed over the surface so as to exclude moisture. The Author has tried decklights as a roof, but has found it impossible to

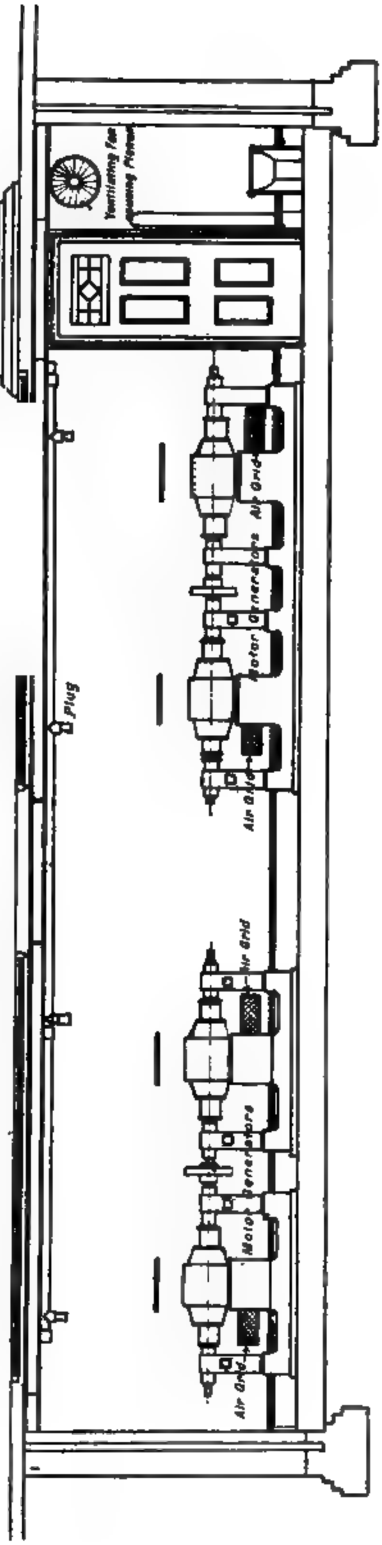
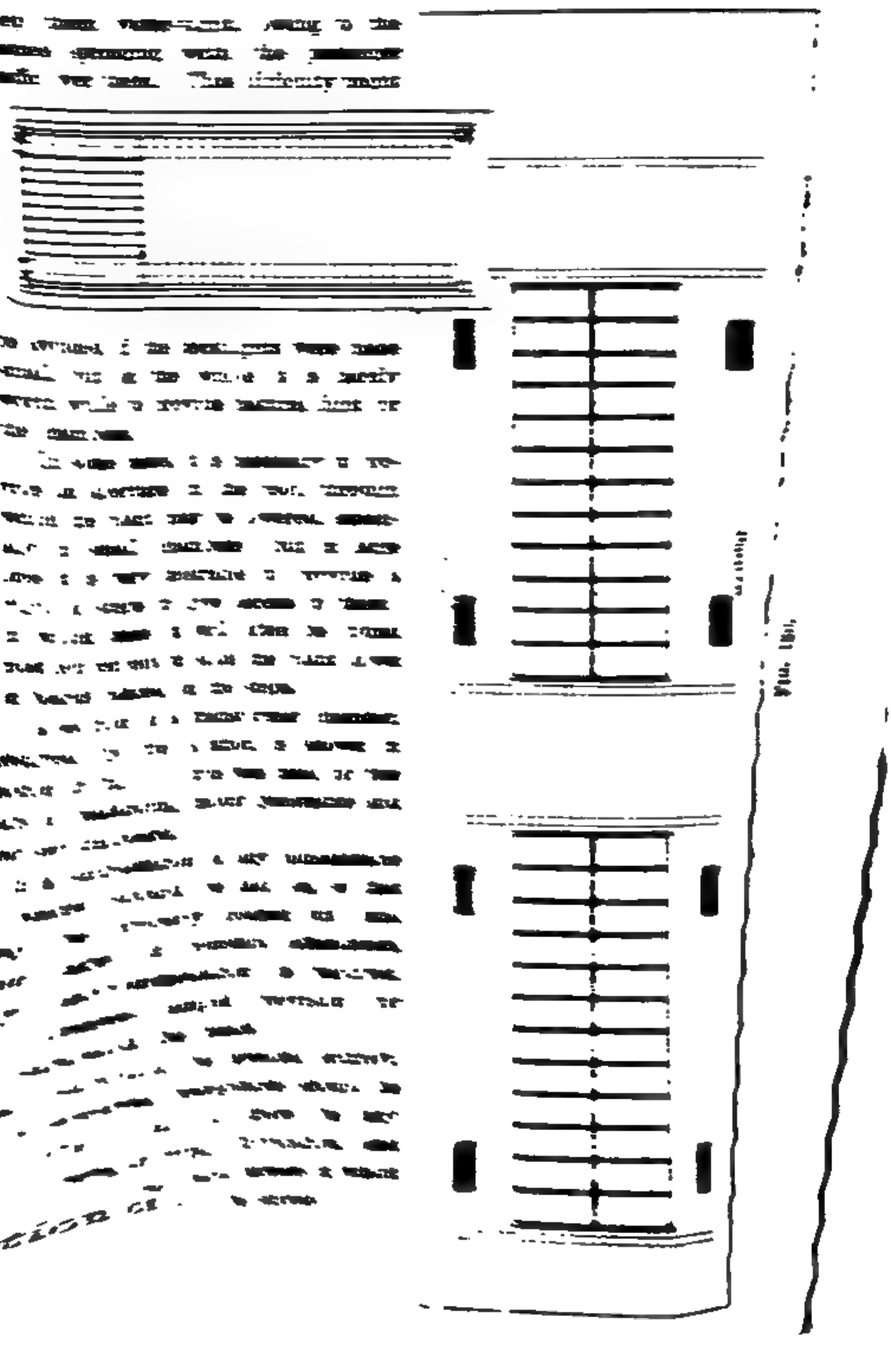


FIG. 18B.



The ventilation should be wholly on the plenum system, one or more fans drawing air from the outside and discharging into the chamber, suitable outlets being of course provided. The air will then be under a slight pressure, and there will be no tendency to draw coal, sewer, or other noxious gases into the chamber from the adjacent soil.

In sub-stations constructed above ground, the buildings do not differ in their general features from those constituting the generating station. They will probably have to be of a somewhat more elaborate and attractive elevation, because they will often be placed in the midst of high-class property. They will require good ventilation, on the same system as that recommended for the engine room.

In the case of battery sub-stations, the floors and the walls to a height of at least three feet should be covered with a good thickness of asphalte. The floors should be given a very pronounced slope to one or more points, at which should be placed drains, so that the place may be thoroughly swilled down. Ventilation should be provided for by a powerful blower, so as to clear the acid fumes away. Exhausters should not be employed, as the acid-charged air would have to pass through them. A separate room for the switching and charging apparatus should be provided, so that it may be kept away from the cells.

CHAPTER VIII.

CHOICE OF SIZE AND TYPE OF PLANT AND GENERAL DESIGN OF STATION.

The type of plant to be adopted depends, first of all, upon the system of generation; secondly, upon the nature of the load to be expected; and, lastly, on the size of the station.

There can be no question whatever as to the superiority of direct driving over any method of gearing, whether belts, ropes, or chains be employed. It is more efficient, more reliable, much safer, effects an enormous saving in upkeep, and, lastly, reduces the floor space required to the smallest possible amount.

As regards the best speed for running, considerable difference of opinion exists. Both high and low speed plant have given excellent results. For small continuous current machines, up to say 250 kilowatts capacity, a saving in the cost of the dynamo is effected by running at a high speed, but for large machines the saving is much reduced; for large powers of from 1500 to 3000 or 4000 kilowatts, the slow running plant is probably the cheaper. For alternating current plant, a slow speed is suitable for considerably smaller sizes.

High speed engines are in great favour in this country, while in America and on the Continent the tendency is to prefer such as run at slow speed. There are several makers of most excellent high speed engines in this country, and the workmanship and materials employed so nearly approach perfection that the repairs, in spite of the high speed, are very small. At the same time, when anything does go wrong, an ordinary fitter is frequently unable to effect the necessary repairs, and the makers have to be called in. Again, such engines cannot be overloaded in case of emergency to the same extent as ordinary slow speed engines, and in the event of a hot bearing they are more likely to be thrown out of action, and cannot be so readily 'nursed' as can slow speed engines.

For large sizes the term 'high speed' becomes rather a misnomer, the speed dropping greatly as the capacity is increased.

Some doubt appears to exist as to whether high speed engines are suitable for machines generating current for traction purposes. There seems to be no inherent reason why they should not be, but there is the important consideration that all the standard dynamo machines for this class of work are built for slow speeds, and hence, if advantage is to be taken to the full of the accumulated experience embodied in their design, high speed engines are excluded.

A strong point of the best known high speed engines is the small amount of attention required while running, and for small stations there can be little doubt that they are the most suitable, whether the current generated be continuous or alternating. Where freedom from all vibration is of paramount importance, extra high speed engines in the form of steam turbines are of great value.

High speed engines may be used with advantage in stations of moderate size, wherein the size of unit does not exceed say 500 I.H.P., or at most 1000 I.H.P.; but above this the Author is of opinion that slow speed engines running at speeds between seventy-five and a hundred revolutions per minute are to be preferred.

The class of engine demands much consideration. The advisability of using triple or quadruple expansion engines has been much debated, and the question cannot even now be regarded as finally settled. Practically the only argument in their favour is that the steam consumption per I.H.P. is less, under favourable conditions, than that of compound engines. At the most, this saving does not amount to more than ten per cent. of the coal used; under the conditions of central station work it is doubtful whether there is any saving at all. Whether the load be a lighting or traction one it is necessarily variable, and, no matter how well chosen the size of generator may be, there must be times when the load on all running is not the maximum. At light loads the efficiency falls off, and the saving disappears.

Even supposing the saving in fuel be effected, and the capital expenditure on boilers be consequently diminished, there are items of expense to be set against this economy. The engine has more parts, and its complication is very sensibly greater than that of a compound; it is in consequence substantially more costly in the first instance, and also for maintenance, while the risk of breakdown is increased directly as the complication. This augmentation of cost will be found to much more than counterbalance the saving on the boilers, and in all probability to more than wipe out the saving in coal, even if there be any at all. Whatever saving could be effected in this direction is after all only on a comparatively small percentage of the running costs, not on the whole amount. This matter is more fully discussed in Chapter XV.

The present position may be summed up by saying that quadruple

expansion engines are certainly undesirable for central station work, and that it is very doubtful whether the use of triple expansion engines can be justified.

In systems in which three-phase current is used to run rotatory converters, it is very doubtful whether the turning moment given by simple compound or three-crank triple expansion engines is sufficiently good. In all probability the most suitable engine is a three-crank one, in which each crank has a tandem compound engine connected to it.

The type of plant should be so chosen that it will answer equally well for lighting or traction, for, sooner or later, nearly all towns will have their tramcars run electrically.

The advisability of combining the lighting and traction stations has been much discussed, but the consensus of opinion is certainly in favour of their combination. It is difficult to see how any other conclusion could be arrived at. Even supposing that the two sets of plant were kept quite distinct, it could not surely be maintained that they would cost *more* to operate if housed beneath one roof. But there must of necessity be a saving varying in amount with the system adopted.

Whatever the system, there is one substantial saving common to all which is effected by combination, namely, the radiation and other standing losses. Both lighting and traction plant experience periods of small demand. In the case of lighting, the small demand extends over many hours; in the case of traction, over, perhaps, eight hours, and the light load in the latter case occurs during the time of light load in the former. In either case the losses from idle plant are of the same nature, though of less magnitude in the case of traction. These losses are, briefly, interest charges on capital, which go on uniformly, whether the plant is at work or not; and the waste arising from the fact that the boilers and steam pipes have to be maintained at a uniform temperature throughout the period of small demand; while, thirdly, men must be kept in attendance at the station, and the cost for their wages is the same, however much or little work the generators are doing.

Now, if the lighting and traction plants are made common, the losses through standing idle are necessarily diminished, for, instead of keeping two staffs of men idle and two sets of boilers and steam pipes hot, only one is required, while the idle capital is reduced by the amount of plant held in reserve being less.

If the system be a low pressure one, it will probably not be feasible to run the lighting and traction loads simultaneously off the same machines, though every machine will be suitable for either purpose; but in high pressure systems the same generator can supply current for both purposes simultaneously, and there is then the further gain that the generators can be made larger individually, and, in consequence, the initial cost per horse-power for the plant be reduced, and also the space occupied, thus lowering

the standing charges for land, buildings, etc., while the running cost for attendance is materially less per unit generated.

Another large saving which is independent of the system of supply is on the score of supervision, that is to say, engineers' salaries and management expenses; while the cost of the repairing staff, which is of substantial magnitude in a large station, together with that of the repairing plant, is also greatly reduced in proportion by combination. Practically speaking, the tools and repairing staff would have to be doubled for two separate stations.

For low pressure systems, it will be found convenient to have the machines wound to give the standard pressure, say 440 volts, *plus* whatever the required excess may be to compensate for the drop in the feeders by variation of the field by the shunt winding; while a series winding for use only when working on the traction load should be provided, enabling the machine to run compounded or over-compounded, as may be required.

In high pressure systems, the generators will be identical for the two purposes, the only variation being on the transformers, which must usually be kept separate for the two classes of load, though interchangeable for either purpose.

The amount and form of the reserve plant is important. The reserve may either take the form of additional plant over and above that required to deal with the load, or of possible safe overload in the machines running.

The Author is strongly of opinion that the latter form is to be preferred. When reserve plant is required, it is almost always wanted at short notice, owing usually to the sudden breakdown of a running machine. Now, if there be a reserve capacity in the remaining machines, the standby can be called into operation instantaneously, and the faulty machine be taken out; whereas, if another generator has to be started up and switched in, possibly with some difficulty if the system be an alternating one, there may be serious delay.

Again, this running reserve is of great use in the case of fog or darkness coming on suddenly, enabling the running machines to keep up the supply until there has been time to supplement them.

Plant that is not working at its utmost capacity, having a large factor of safety in consequence, is less likely to break down, and does not deteriorate so rapidly. Finally, the cost of the same amount of reserve is much less than in the form of additional machines.

Hence, everything is in favour of reserve capacity in every machine.

In designing a station the ultimate final capacity which it is intended to have should be kept in view, and the whole of the arrangements should be planned out in their entirety, although they may not be carried out for many years. In this way, and in this way only, can the economical and satisfactory extension of the original plant be provided for.

A most important initial consideration in designing a station is the

determination of the size of generator or generating 'unit' as it is somewhat infelicitously termed. The factors governing this are (1) the total capacity of the initial instalment of plant; (2) the ultimate probable capacity of the station; and (3) the percentage overload considered necessary as a reserve.

It is important to estimate correctly the amount of plant required during the first stage of operations of the undertaking. This should cover a period of, say, three years; it is manifestly wrong to have to extend at the end of the first year, for extensions while in progress are a source of much inconvenience, and tend towards diminished efficiency in working.

If the estimate of the amount of plant required be excessive, the undertaking will be burdened with an unnecessarily heavy capital expenditure; while if it be too low, the size of machine fixed in the first instance will be inconveniently and needlessly small.

It may here be well to refer to the reprehensible practice of putting in two machines, or, in some instances, even one machine as the initial instalment. The excuse for such a course is that extensions will soon be required, and that the size of machine will then be more in conformity with the requirements of the station. This is simply an admission that the estimate of the plant required has been deliberately made too low, and the full amount necessary to be installed in the first instance has not been provided. If two machines, each having a capacity equal to the full load expected, be provided, the reserve is unnecessarily large; while if only one be fixed, the risk of breakdown and consequent utter collapse of the supply is quite unjustifiable.

Assuming that the total initial capacity has been correctly gauged, the next point to be settled is: among how many generators shall this be divided? This will be determined by the percentage reserve considered necessary, and by that alone. The condition is, that if one machine break down, the remainder shall not be overloaded more than a given amount. If the permissible overload be 33 per cent., four machines will be the number to be provided; if 25 per cent., five; and if 20 per cent., six.

In this manner, then, should be settled the size of the first machines; the next thing to consider is the system on which extensions should be carried out. If we assume that the original scheme of reserve plant is adhered to, the condition to be fulfilled is that each fresh instalment shall be so proportioned that if one of the new machines break down, the remainder of the plant will not be overloaded more than the predetermined amount. The size of the added machines will depend on the magnitude of the extension decided upon, but the choice of this magnitude will be between certain definite amounts. Thus the minimum extension possible, if the rule is to be followed, will be one machine, the size of which must be one-third of the capacity of the original installation, if the percentage overload be 33 per cent. The next step to the minimum is two machines, each having a capacity one-half that of the initial instalment, and so on.

In order to more fully illustrate the above principles, the following table has been worked out by the Author. It is assumed that the initial installation comprises machines aggregating 2000 H.P., while the final capacity is about 65,000 H.P. The table then shows the various stages of development.

PERMISSIBLE OVERLOAD 33 PER CENT.

Totals . .	16	63,018	20	59,959	14	64,000	22	64,000	13	56,000	16	58,000

* *Note.*—The last instalment if carried out on the same lines would make the total capacity far in excess of that intended, so the last but one is repeated.

An inspection of this table will show, firstly, at what a very early stage in the development of a station it becomes safe to use machines of very large power; it is, indeed, most remarkable how large they may be without involving greater risk of interruption in supply than in the first instalment.

So rapidly does the size grow that the rule for a station of the size contemplated cannot be adhered to on account of the machines becoming impracticably large. At precisely what point this takes place it is difficult to say. The Author has arrived at the conclusion that 5000 H.P. is as large as it is expedient to attempt at the present time, though it is probable that this will be at least doubled in the future.

Assuming, for the sake of illustration, that 8000 H.P. is the limit, then as soon as this size is reached the rule must be departed from, and all the fresh instalments become made up of machines of uniform power.

Another point to be observed when inspecting the table is that adding machines one at a time destroys uniformity, each succeeding one being larger

than the last. The most symmetrical arrangement appears to be that in which two are added at a time.

Now, on consideration, it will be seen that in a large station we have two series of generators of equal size, one series small, the other large, and these are united by a series of machines gradually increasing in size. The larger the first instalment is made, the less is the disparity in size of the machines in the two groups of similar generators, and the smaller is the number of the connecting series. Hence it will be seen that if the initial instalment can only be made large enough, all the generators can be of equal size, and absolute uniformity and interchangeability can be secured throughout. It is true that this implies a first installation of 20,000 H.P., but this is by no means beyond the bounds of practice in the future, for stations of 100,000 H.P. may be expected before very long.

There is a consideration, however, which must not be lost sight of in settling the size of machine, namely, the minimum load on the station. The smallest machine must not be greatly in excess of this, or the arrangement will be uneconomical.

A point that will not escape notice in an inspection of this table is that, by following the figures given, the extensions would be carried out by ever-increasing amounts. It must be understood that this is not advocated as being the proper policy under ordinary circumstances, though in exceptional cases, especially when large extensions of the area of supply are being undertaken, it may well be, but it is merely intended to show by the table what are the principles on which it is safe to put down large generators, if it be desired to have them as large as possible, and, incidentally, at what an early stage it is safe to employ very large sizes.

If it be desired to augment the plant by equal amounts, the reserve will become more ample as time goes on, for any size less than that given by the table will give more than the reserve allowed for therein.

Thus, the permissible overload being 33 per cent., and the machines having been added two at a time, suppose the last instalment has been two generators of 2000 H.P. each, and it is considered that two of 4000 H.P. would be too large an extension, it might be decided to put down two more of 2000 H.P. each. In this case, if one of the new machines broke down, the remaining plant would only be overloaded to the extent of 20 per cent. instead of 33 per cent. If the remainder of the extensions be carried out by equal instalments of the same size of generator, there would be, when the final capacity of 64,000 H.P. was reached, 36 generators, and the breakdown of the largest would only overload the remainder to the extent of 3½ per cent.

As the size of engine is increased, it is natural that the size of the individual boilers should be augmented, but in this case the increase in power cannot be carried to anything like the same extent. The maximum size

attainable will vary considerably with the type of boiler; it is difficult, for instance, to make a Lancashire boiler that will supply steam for a compound engine developing more than about 500 H.P., while a water-tube boiler may readily be made two-and-a-half times as large, and a marine boiler larger still.

If a large number of boilers be employed, the ground space occupied will be very great; this would not in itself be of much moment, provided the land were cheaply obtained; but, apart from the cost of the site, there is the serious disadvantage that long steam pipes are required, and this introduces great loss from radiation, and consequent waste of heat, together with difficulties in connection with expansion and contraction of the pipes.

Large boilers, besides being compact, possess the further advantage that the number of parts is greatly reduced. Each boiler of necessity has a number of fittings, valves, etc. All these are a source of expense, and require trouble and expenditure of money to keep in order; the large sizes cost much less in proportion, and practically give no more trouble, than the small; hence the reduction of their number is a clear gain.

Inasmuch as the volume of any object increases as the cube of its linear dimensions, while its surface only increases as the square, it follows that large boilers have less radiating surface than small for each pound of water evaporated per hour.

The size of boiler should, for the reasons stated, be as large as possible in a station of considerable size; in smaller stations it must be determined by the capacity, the size being so chosen that the number will admit of a boiler being put off for cleaning or repair without inconvenience.

It is very desirable to so place the boilers that each engine has adjacent to it a sufficient number of boilers to supply it with the steam required. The connecting pipes need not then be long; and very large pipes can be avoided, there being no necessity to provide main steam ranges capable of carrying large volumes of steam. All that is necessary is to provide for sufficient steam for one engine to be carried. A reference to figs. 14 and 15 will make this clear. Suppose there are three engines, each requiring two boilers. If the arrangement be that shown in fig. 14, all the steam has to pass through the pipe A B, whereas in the other arrangement there is no pipe larger than the branches to the engines.

The efficiency of the station depends greatly upon the skilful laying out of the pipe system. In the early days of central stations it was considered essential that there should be two paths for the steam from the boilers to the engines. This was accomplished, either by means of a complete duplicate set of pipes, or by a so-called 'steam ring' in which the outgoing pipe returned to the boilers, forming a complete ring, the steam being able to leave the boilers in either direction. The ring system was by far the most popular.

There can be no doubt that the duplicate system is exceedingly wasteful of heat; and when one range is off, leaky valves, of which a certain number are practically unavoidable, lead to a considerable loss of steam. On the other hand, the ring system entails trouble also by the necessity for large and costly valves, and by expansion and contraction with change in temperature, besides being wasteful of heat also, though not to such a marked extent as the other system.

There has lately arisen a strong reaction against both systems, and it has

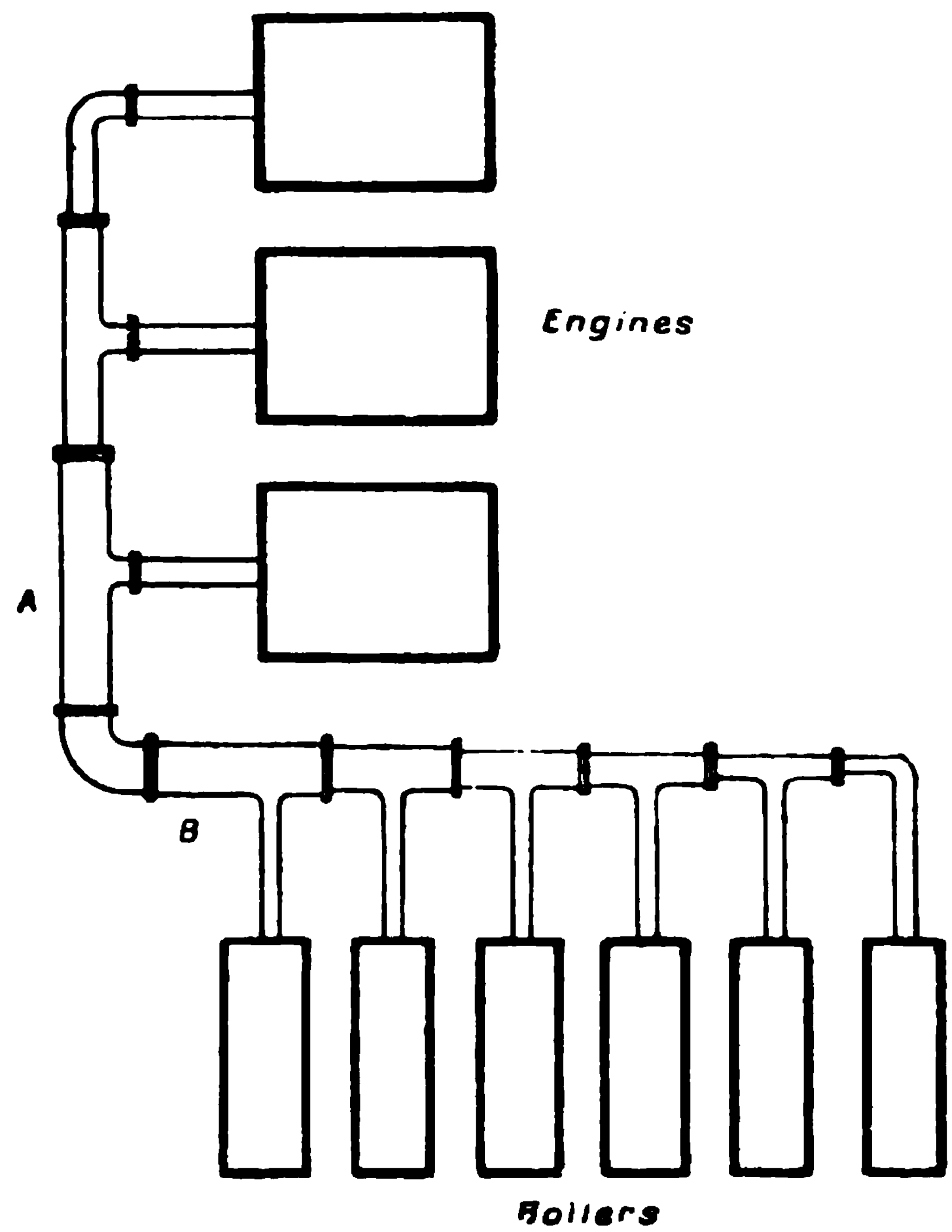


FIG. 14.—Mode of arranging boilers and engines.

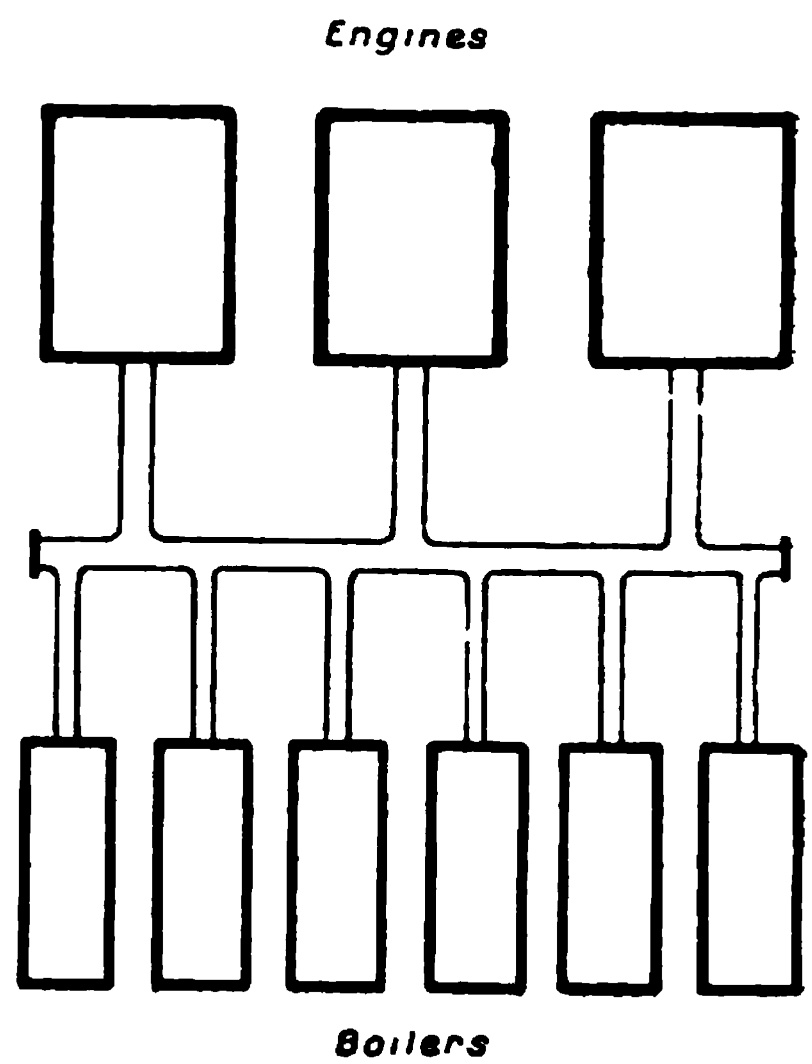


FIG. 15.—Mode of arranging boilers and engines.

been emphatically stated that there is no necessity for either. It is difficult to believe that such an opinion can be seriously held. It is surely obvious that to depend for continuity of supply on the tightness of every joint on a large system of piping in a plant that has to run year in year out is little short of madness. The fact of the matter is, that duplicate mains and ring systems are only adapted to stations of moderate capacity, and that other means must be sought of securing against breakdown in large ones. The essential point is to provide a system which shall admit of every joint or leakage being made good without interrupting the supply of steam to more than a small fraction of the plant, and also that the failure

of any portion of the pipe system shall not involve even a momentary interruption of the operation of the plant.

Similar remarks apply to the boiler feed pipes. The objections, however, to a duplicate system here are not nearly so cogent as in the case of steam ranges, and probably the simplest system is a duplicate one.

The position for the main switchboards must be chosen with great care. They must be so fixed that they are not exposed to risk of damage by water, steam, oil, broken belts or ropes, etc., and so that there is easy access to them for the mains, both from the generators and from the streets. In some cases it may be desirable to have a portion of them, if not all, in a separate fire-resisting building. Ample space must be allowed so that the switchboard can be extended to meet the requirements of the station when complete.

CHAPTER IX.

BOILERS.

THE subject of boilers is a very wide one, and is of vital importance to the successful working of a central station. It is manifestly impossible within the scope of this book to attempt to give an account either of the principles underlying the action, or of the various types of boiler available, or of the details of their construction. For these matters the reader is referred to the numerous excellent works dealing with the subject. It is only necessary here to consider the special conditions which exist in a central station, and the means at hand for meeting them.

The office of the boiler is to effect the complete combustion of the fuel, to abstract the heat from it, and impart it to the water. The methods by which this result is attained present an endless variety. Each particular type has some special merit of its own; one is economical, and has a large water space, but is bulky and cannot work above a certain rate; another can be made to give steam very rapidly, but has a very small water space; yet another is exceedingly compact, but steam cannot be got up quickly without injury to the boiler. Again, some are very much better adapted to high pressures than others; while some, possessing great advantages in certain respects, are exceedingly costly as regards repairs.

Let us consider what are the conditions in a central station, and first those common to all. Steam must always be available throughout the twenty-four hours, but the rate at which it will be required will vary enormously. From midnight to 6 a.m. the demand will usually (in a lighting station) be very small; then, in winter, will come a considerable draft, then a falling off; and then, at dusk, an abrupt increase in the rate at which steam must be given off, rising rapidly to a maximum which will endure for a varying period, and will then gradually fall off. The exact amount and time of these variations can be foreseen with considerable accuracy for any given period of the year; but besides these, there are exceedingly sudden and quite unexpected demands for steam, which may arise in many towns, especially in manufacturing districts, through fog in winter and thundery weather in summer. On these occasions, the evening

maximum demand may be reached, or even exceeded, in an incredibly short space of time.

Now it will be obvious that, even under normal conditions, it is impossible to let the boilers become cold between one evening and the next, and, in order to meet sudden demands, there must be a large reserve; hence it follows that for each season of the year a certain number of boilers must be kept under steam, a large proportion being kept banked up during the night and for a portion of the day. It is thus clear that the boilers should present the smallest possible radiating surface, so that the amount of heat lost may be kept small.

Next, the boilers must be such that they are economical when fired at rates varying over a considerable range, and they must be capable of being forced, *i.e.*, of having their rate of steaming suddenly increased, without detriment.

What has to be aimed at is to provide boilers of such type and in such number that when supplying steam for, say, the hour or two before full load, and for several hours after it, they will be working most economically; while for the hour or so that the actual maximum is attained, they will supply the steam required with forcing, not necessarily so economically.

There are, in fact, two opposing considerations. On the one hand, there must not be too many boilers, or the loss from radiation, through having a large number idle during the greater part of the twenty-four hours, will be enormous; while, on the other, the boilers must not be too few, or they will not furnish sufficient steam at maximum load.

Turning from the purely engineering considerations to the commercial aspect, the first cost of the boiler, the cost of maintenance, and the space occupied, are the most important considerations. The first cost will vary with the type of boiler and with the steam pressure, the importance of the space occupied will vary very greatly with the situation of the station; it may be comparatively unimportant, or it may be the determining factor in choosing the boiler.

A brief glance at the various types of boiler available is essential in discussing this matter; there is an almost endless variety, but those principally used in central stations are: the Lancashire, the Galloway, the Cornish, the Water-tube, of which the Babcock and Wilcox is a representative example, the Marine Wet-back and Dry-back, the Economic.

The Lancashire boiler is an internally fired one, and comprises a cylindrical shell with two cylindrical tubes in which the furnaces are placed. In large sizes, which, however, are but seldom used, three furnace tubes are employed. The boiler is set in brickwork, the flues being so arranged that the gases pass along the furnace tubes, then under the shell to the front, thence along the sides of the boiler to the chimney. This boiler has been made successfully for all pressures up to and including 200 lbs. per square inch working pressure. Its distinguishing features are: (1) high efficiency at

moderate rates of combustion; (2) reliability and freedom from repairs; (3) large water space, involving ability to meet sudden rushes of demand of short duration; (4) adaptability to bad water, as it can be easily cleaned; (5) large floor space required; (6) inability to be greatly forced economically.

The Galloway boiler is similar to the Lancashire, except that the two cylindrical flues are joined into one elliptical one at the back, and the flues are crossed by conical tubes, some thirty in number, the functions of which are to stiffen the flues, increase the circulation of the water, increase the heating surface, and baffle, and so intermix, the gases. It is usual to put a few, about six, such tubes in ordinary Lancashire boilers.

The Cornish boiler is similar to the Lancashire, except that it has only one cylindrical furnace tube instead of two. It is set in brickwork, and the course of the gases is similar to that described for the Lancashire. It is only suitable for small stations.

The Watertube boiler is an externally fired one; the best known representative of this class is the Babcock and Wilcox. It consists of a number of tubes inclined from the front backwards; the tubes are staggered, and are connected in vertical sections at each end by a zigzag passage ending in a cylindrical horizontal drum, placed above the tubes, which serves to collect the steam and to hold some water, small in amount compared with the Lancashire or Cornish boiler. The boilers are usually set in brickwork, and the course of the gases is upwards across the tubes, downwards across the tubes, and finally upwards so that the tubes are traversed three times. The weight of the boiler is not taken by the brickwork, the whole boiler being slung from a steel framework so that it is free to expand and contract. The chief features of this boiler are: (1) moderate floor space; (2) ability to raise steam rapidly; (3) good circulation of water which diminishes the stresses on the boiler and enables steam to be got up quickly from the time of the boiler being quite cold; (4) adaptability to very high pressures; (5) ease of erection in confined situations, the boiler being transported in sections; (6) facility for repair, it being only necessary to renew the portion actually deteriorated; (7) not well adapted for use with hard or corrosive water; (8) repairs greater than with Lancashire; (9) small water space and consequent difficulty in meeting sudden rushes without serious variation in pressure; (10) cost of setting high. It is a moot point whether they give wet steam or not, some users stating emphatically that they do, while others are equally emphatic that they do not. If the steam be superheated, the defect, if it exists at all, of course disappears.

Another tubular boiler of which highly satisfactory results are anticipated, but which has not yet come into extended use, is the Niclausse.

The Stirling is a well-known boiler of this class, which is coming into increasing favour for central station work.

The Marine boiler consists of a very short cylindrical shell of relatively

large diameter, with two cylindrical flues similar to those in a Lancashire boiler; these unite at the back in a combustion chamber from which small tubes pass, parallel to the large flues, to the front of the boiler and thence to the main flue. These tubes do not extend quite to the back of the boiler, a water space being left behind the combustion chamber. Such boilers may be placed back to back and fired from both ends. They require no setting. The most noteworthy points about these boilers are: (1) exceedingly small floor space required; (2) small radiating surface; (3) good economy; (4) heavy and difficult repairs; (5) entire unsuitability for use with bad water; (6) the circulation of water is very poor, and the boilers require a long time to get up steam from being cold.

The Dry-back boiler is similar to the last, except that the tubes go quite to the back, and, instead of having a combustion chamber within the boiler, this is formed behind it by setting the boiler in brickwork. In some cases the gases, instead of going directly into the main flue from the small tubes, are taken round the shell.

In large sizes of both Wet-back and Dry-back, three furnaces are used instead of two.

The Economic boiler is similar to the Lancashire boiler in having a cylindrical shell and two cylindrical flues, but is much shorter, and the upper portion is traversed by a number of tubes parallel to the large flues, as in a Marine boiler. The boiler is set in brickwork, and the course of the gases is along the large flues to the back, thence by means of a combustion chamber through the small tubes to the front, into smoke boxes at the front, and thence along flues at the sides and beneath the boiler, being divided into two portions by a central wall, and so to the main flue. This boiler (1) takes but small floor space; (2) has less radiating surface than a Lancashire boiler; (3) is not so easily cleaned; (4) is liable to require somewhat more repairs; (5) requires rather greater draught.

It will now be well to compare the boilers from various points of view, and first it may be assumed that the cost of land is low, so that economy of space is not a ruling consideration.

Comparing the various boilers from the point of view of cost per 1000 lbs. of water evaporated per hour when the boiler is steaming at its most economical rate, we find the following, if the pressure be 150 lbs. per square inch, the boiler being of such a size as will evaporate about 7500 lbs. of water per hour:—

Kind of Boiler.	Cost at Maker's Works.	Delivered on Site, including Setting and Erection.
Lancashire,	£63	£75
Galloway,	79	89
Babcock and Wilcox,	62	72
Marine wet-back,	87	...
Economic,	59	77

The price of a boiler will vary greatly with the steam pressure, and will increase more rapidly with the pressure according to the type, some forms of construction lending themselves much more readily to cheaply dealing with high pressures than others.

The following table brings this out very clearly. It shows the cost of the boiler at the maker's works (without setting) per 1000 lbs. of water evaporated at pressures varying from 80 to 200 lbs. per square inch, the boilers being of the same size as in the last table.

Kind of Boiler.	Cost, Pressures in lbs. per Square Inch.					
	80.	100.	125.	150.	200.	250.
Lancashire, ...	£43	£47	£54	£63	£74	...
Babcock and Wilcox, . .	...	60	62	62	63	£65
Marine wet-back, . .	...	75	81	87	100	119
Economic, ...	45	49	54	59	79	...

So far we have considered the first cost of the boilers; the cost of their upkeep is, however, of considerable importance. It is exceedingly difficult to obtain any reliable figures in connection with this; those given are little better than estimates.

Kind of Boiler.	Life of Boiler.	Time before all Tubes had to be Renewed.
Lancashire, ...	20 years.	...
Babcock and Wilcox, . . .	30 ,,	20 years.
Marine wet-back, ...	20 ,,	15 ,,
Economic, ...	15 to 20 ,,	12 to 15 ,,

In each case it is assumed that ordinary repairs, including the renewal of tubes in the case of tubular boilers, are effected. These will be much the smallest in the case of Lancashire boilers; it is difficult to say which will be heaviest of the other three.

The efficiency of the boiler, that is to say, the percentage of heat in the fuel utilised by it, is obviously a matter of vital importance. This will vary greatly with the rate of combustion, and the falling off of efficiency as the rate is increased will be different for different types of boiler.

Unfortunately, although hundreds of carefully made experiments have been carried out, it seems impossible to deduce any accurate comparison of the various types, the results for each varying so greatly among themselves. If a certain figure for the efficiency be selected, whether it be high or low, it seems as if it might be found among the tests of every type.

A very valuable collection of tests is given in Mr Bryan Donkin's

"Heat Efficiency of Steam Boilers." A summary given by him enables the boilers above referred to, to be compared in some measure.

Kind of Boiler.	No. of Experiments.	Mean Efficiency of two Best Experiments.	Lowest Efficiency.	Mean Efficiency of all Experiments.
Lancashire hand-fired,	107	79·5	42·1	62·4
Lancashire machine-fired,	40	73·0	51·9	64·2
Cornish hand-fired,	25	81·7	53·0	68·0
Babcock and Wilcox hand-fired,	49	77·5	50·0	64·9
Marine wet-back hand-fired,	6	69·6	62·0	66·0
Marine dry-back hand-fired,	24	75·7	64·7	69·2

It will be seen what an enormous variation there is between the highest and lowest results obtained. In all the tables given in this chapter the boilers are without economisers. This particularly affects the Lancashire boiler, which is hardly ever, and never should be, used without one. This accounts for the apparently low efficiency of the boiler in the table. It is greatly raised by the addition of the economiser, but at the same time the price and floor space are materially augmented.

In many cases the cost of land is high, so that the amount of floor space required by the boilers becomes of great importance. On this basis the boilers compare as follows, the boiler being of the same size as those previously compared, the floor space being given for the complete boiler without firing floor or main flue :—

Kind of Boiler.	Floor Space in Sq. Ft.
Lancashire,	408
Galloway,	371
Babcock and Wilcox,	200
Marine wet-back,	120
Economic,	210

The choice of boiler will be influenced to some extent by the steam pressure determined on. In this connection it may be pointed out that at a certain stage in the life of a boiler it is no longer safe to work it at the pressure for which it was built; at the same time, if that pressure be reduced by a few pounds, the useful life of the boiler may be considerably extended. It would seem wise, therefore, to incur the comparatively slight extra initial expense of building the boiler for a working pressure, say, from 20 lbs. to 50 lbs. per square inch in excess of that which it is actually intended to use, so that the period at which it is necessary to reduce the working pressure below that of the station is greatly deferred. An additional advantage is that before the boiler has begun to deteriorate there is a considerable margin of safety, and safety valves can be so loaded as to render

their blowing under ordinary circumstances very remote, and thus a source of considerable loss is avoided, for, where the margin between working and blowing off pressure is small, it is difficult to so set the valves that they will not let by. Yet another point in favour of the course suggested is that it enables a good start to be made before the heavy load comes on, a few pounds in hand being an immense boon.

For pressures up to 200 lbs. per square inch any of the boilers described may be used; but for pressures exceeding this it is probably best to employ tubular boilers; while, for many reasons, they are to be preferred for pressures exceeding 150 lbs. per square inch.

The capacity of the station will also influence the type of boiler selected. In a large station everything points to increasing the size of the unit of plant, and though, as has been shown in a previous chapter, this can readily be done in the case of engines and dynamos, boilers cannot so easily be increased in size. Practically speaking, the Lancashire boiler reaches its limit of size when it is 30 feet × 8 feet, for above this size the plates necessary become unduly heavy, especially if high pressures be used, as they are almost certain to be in large stations. Thus, in a station of 50,000 H.P., a capacity by no means likely to be uncommon in the future, there would have to be some 120 boilers. Recalling what has been said in Chapter VIII., this means multiplication of fittings and consequently unnecessary expense and cost of maintenance, very large radiating surface, and, worst of all, the large floor space necessarily occupied involves very long steam pipes, with the accompanying evils of very wasteful radiation and great expansion, which is most difficult to satisfactorily deal with.

The Babcock and Wilcox boiler, by virtue of its construction, lends itself well to increased size of unit, and this is a great argument in its favour in large stations.

The largest size of boiler of each type suitable for a pressure of 150 lbs. per square inch, which it is practicable to construct at the present stage of development, is as follows:—

Kind of Boiler.	Pounds of Water Evaporated per Hour at Economical Rate.
Lancashire,	10,800
Babcock and Wilcox,	20,000
Marine wet-back,	14,400

The Lancashire quoted is of abnormal size, being 30 feet by 9 feet 6 inches; very few firms would make one larger than 30 feet by 8 feet 6 inches for this pressure; this boiler would evaporate about 9000 lbs. of water per hour.

It is interesting to note how rapidly the price of a Lancashire boiler increases with its diameter. A boiler 30 feet long, built for a pressure

of 150 lbs. per square inch, would be increased in price 11 per cent. for an increase in diameter of 6 inches above 8 feet, 24 per cent. for 12 inches, and no less than 38 per cent. for 18 inches.

Without attempting to lay down any general rule, it may be said that in stations of moderate size, the Lancashire, where there is space for it and its economiser, is probably the most satisfactory of any, inasmuch as it is economical, easy to manage, requires practically no repairs, is thoroughly understood, and can be made by many different firms, thus admitting of ample competition as to price, has a large water space, and can be banked up without excessive waste of heat. The Babcock and Wilcox boiler undoubtedly runs the Lancashire boiler close, and in cases where diminished floor space is of importance, or very high pressures are required, or large units are imperative, the scale is turned in its favour. Where extremely small floor space is paramount, the Marine boiler is efficient and useful, but it has the serious drawback of bad circulation, the repairs required are apt to be excessive, and for very high pressures it is less safe than a Water-tube boiler.

The Economic boiler has been considerably used, and may be adopted with great advantage in certain cases.

CHAPTER X.

SYSTEMS OF DRAUGHT AND ECONOMY OF WASTE HEAT.

WHEN fuel is burnt, the combustion has to be maintained by supplies of air brought into contact with the fuel, and the products of combustion have to be removed; that is to say, a circulation has to be produced, or, in other words, a draught of some kind is necessary.

A draught is a difference of pressure causing the gases to move from a region of high pressure to one of low. This difference of pressure is produced in practice in three ways, viz., by (1) natural draught, given by a chimney containing heated and therefore rarefied air; the weight of this column of air being less than that of one composed of the ordinary atmosphere, a difference of pressure is set up; (2) induced draught, caused by a fan placed in the flue, which, by removing the gases, causes the pressure in the flue to be less than that of the atmosphere; (3) forced draught, caused by a fan or steam blowing air into the furnaces, and so causing the pressure there to be greater than in the flue.

Each system has its special merits. As regards the relative cost, the capital cost of constructing the chimney is much greater than that of the fans; but, on the other hand, the depreciation and cost of upkeep of the chimney, if well built, is practically *nil*, and the draught is absolutely reliable and free from risk of breakdown. On the contrary, the cost of maintaining the fans and the motors or engines driving them is considerable, especially with induced draught.

As regards the cost of running, the chimney requires the gases to be allowed to escape at a somewhat higher temperature than they do with the fans, but this cost is very trifling, compared with the expense entailed by having to provide power to drive the fans, together with the cost of labour for attention to them. The risk of breakdown with the fans is, of course, considerable, and standby plant is necessary.

With natural draught, the amount cannot be varied between wide limits, nor can it be increased to a high value without undue cost, while with artificial draught it can be varied at will with the greatest ease, and can be increased to any desired extent; this is a very great convenience, as it

enables the boilers to be forced when desired, and it allows of economy being effected by admitting of the use of a very low grade of small coal which can only be burnt with a strong draught.

As compared with induced draught, forced draught has the great disadvantage that, unless great care be taken to shut it off before opening the firedoors, the stoker may be seriously burnt by the flame being blown on to him, and it is also somewhat more trying to the boilers. On the other hand, when forced draught is used, a given weight of air has a smaller volume, and there is no tendency to draw cold air in at undesired points at which leaks may exist.

Natural draught is the most widely used, and is certainly the most satisfactory under ordinary circumstances. Hence it may be as well to consider the conditions governing it. The chimney has a twofold office to perform, viz., to create a difference in pressure and to remove a given volume of gas in a given time. The first condition determines its height, the second its area.

Theoretically, the draught measured in inches of water, given by a chimney H feet high is $7 \cdot 6 \, H \times \frac{T_2 - T_1}{T_2 \times T_1}$, where T_2 is the absolute temperature of the chimney gases and T_1 that of the atmosphere, while the weight of gas removed in a given time is proportional to $\frac{\sqrt{0 \cdot 96 T_2 - T_1}}{T_2}$. It can be shown that the temperature of the escaping gases must not be less than 300° F.

The whole theory of chimneys is in a very unsatisfactory state. There are so many variables and so many considerations that cannot be theoretically determined that no scientific formula that will properly cover them can be given. The actual size and height required for a given installation of boilers is largely a matter of practice, but certain empirical formulæ are employed. There are a number of these in use; two may be given as tallying very fairly with observed results.

The first is Kent's, by which the area A of a chimney necessary to burn F pounds of coal per hour is $A = \frac{0 \cdot 06 F}{\sqrt{h}}$, whence $h = \left(\frac{0 \cdot 06 F}{A}\right)^2$, h being the height of the chimney. In order to allow for the friction due to the sides of the chimney, the effective area may be taken to be $A - 0 \cdot 6 \sqrt{A}$.

The second formula is Smith's, and is similar to Kent's, the only difference being that the constant is 0·0825 instead of 0·06.

In applying the formulæ, the height is usually first assumed, and then the area calculated. It is well to remember that a good margin is of the utmost value, and that it is therefore well to err on the side of having the chimney too large rather than too small.

Chimneys are usually constructed of brick in this country, but in America iron is largely used. Though possibly cheaper than brick, they are

more costly in upkeep, deteriorating much more rapidly, and requiring frequent repainting; such chimneys are also more readily affected by atmospheric conditions.

A considerable amount of experience is required to properly design a chimney, and only general rules can be given. The external diameter at the base should not be less than one-tenth of the height, and the utmost care must be taken to secure a good foundation. The interior should be of uniform section, and be lined with firebrick for the greater portion, if not throughout the whole, of its height. There must be a cavity between the lining and the chimney proper, the two being tied together at intervals, the object being to keep the chimney cool. The exterior of the chimney must taper from the bottom upwards at the rate of from $\frac{1}{16}$ to $\frac{1}{4}$ inch to the foot. It is most important to have the entrances for the flues as symmetrical as possible in order that there may not be more settling on one side than on the other. When the flues enter from opposite sides, a midfeather, formed of firebrick and having a number of perforations, should be built to a height of, say, 50 feet for a 200 foot chimney, so as to direct the two sets of gases upwards. The perforations prevent the gases being baffled. In order to illustrate the construction, an actual chimney is shown in fig. 16: it is 223 feet high, 11 feet internal diameter, and is intended to deal with eleven Babcock and Wilcox boilers, each having a grate area of 72 square feet, and a heating surface of 5140 square feet. The total horsepower to be developed by the engines supplied with steam by these boilers is 14,000 H.P., the engines being compound condensing.

Induced draught and forced draught may be grouped together as mechanical draught. Mechanical draught may be produced by fans, by steam jets, acting on the same principle as the ordinary injector, by blowers in which the air in a vessel of appropriate form is positively ejected, the Roots blower being a representative example of this class, or by compressed air. The last two methods are only applicable to forced draught.

Fans are the most important means of producing mechanical draught, and may, with advantage, be briefly considered. They are of two types: (1) the disc, in which a number of spirally shaped blades cause the air to move parallel to the axis of the fan; and (2) the centrifugal, in which the blades are radial, and the air is drawn in at the centre and discharged tangentially from the ends of the blades. The second type is almost always used for draught purposes.

The action of the fan depends on the air between the blades tending to fly off tangentially as the fan revolves, fresh air being drawn in at the axis to replace it. The amount of vacuum produced depends on the circumferential speed of the blades; the velocity of the air discharged, if the outlet be free, being approximately equal to this speed.

The pressure created by a fan varies as the square of its speed. The

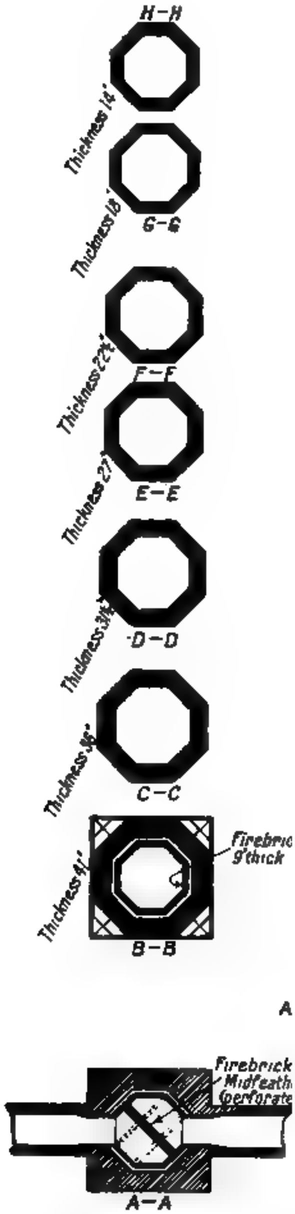

H–H
Thickness 14"
Thickness 18"
G–G
Thickness 22½"
F–F
Thickness 27"
E–E
Thickness 31½"
D–D
Thickness 36"
C–C
Firebric
9"thick
Thickness 41"
B–B
A
Firebrick
Midfeath
(perforate
A–A

FIG. 16.

power required by the fan varies as the cube of the speed. In designing fans the peripheral speed must be made such as to give the required pressure, and the width so proportioned as to allow the necessary volume to pass. Judgment is required to ascertain the most suitable diameter and speed to give the peripheral velocity.

The actual capacity of the fan is much modified from the theoretical capacity by the form and size of its casing, and of the passages through which the air has to pass. It has been found by experiment that a fan enclosed in a case will maintain the pressure corresponding to the peripheral velocity of its blades over any area up to a certain limiting value, beyond which the pressure falls. This limiting area is given by the empirical formula $\frac{DW}{x}$, in which D is the diameter of the fan itself in inches, W the width of the blades at the circumference, and x a constant varying with the type of fan, and of its casing, and having usually a value approximating to 3.

When a fan is required to exhaust hot air, the speed required to produce a given pressure is greater than with cold air. The amount of power required for the higher temperature air will be diminished by increasing the area of discharge above that used for cold air. In other words, the same fan should not be used for moving the same weight of hot air as is used for cold air, the volume of the former being greater. With a properly designed fan, the increase in power required to move a given weight of air, and to maintain a given difference of pressure with air at a temperature of 300° F., is about 50 per cent. as compared with air at a temperature of 50° F. Hence it follows that induced draught systems require substantially more power than forced draught to run the fans. In considering induced draught, it must be borne in mind that, although theoretically no chimney is required, and actually is not necessary for the purpose of producing a draught, yet, practically, one must be provided in order to provide for the inoffensive discharge of the products of combustion; local bye-laws fix a minimum height, which is usually far from small.

Forced draught may be applied either by closing the ash-pits and forcing the air directly into each individual one, or the whole boiler house may be enclosed, and the air in it be kept at the required pressure. The former is the method usually adopted on land.

Fans offer an excellent means of providing the draught with either method, but a steam blast is frequently employed with the former, though it is obviously inapplicable to the latter. A steam blast, while possessing the advantage of very low first cost, is less efficient than a fan, and has the further disadvantage of introducing aqueous vapour into the flues. This is very liable to become dissociated, and interfere with the proper combustion of the fuel

The best known and most widely used form of steam blast is Meldrum's. The blast is produced by means of live steam blown through a nozzle, which carries the air with it by an action similar to that which takes place in an injector. The blast is distributed and reduced in intensity by being ejected from a trumpet-mouthed tube. Valves are provided for controlling and regulating the supply of steam and of air. The ash-pit is closed by means of doors with faced joints, and the air is discharged under the fire-bars. Two blowers are provided for each furnace in a Lancashire boiler. Under proper conditions, the amount of steam required for the blast is 4 per cent. of the steam generated by the boiler. In order to prevent the intensity of the blast damaging individual fire-bars, they are locked together so as to present as uniform a surface as possible. Good results are stated to be attained with this system, which possesses the advantage that very fine fuel can be burnt.

The best example of forced draught in which a fan is employed is Howden's; this is fully described below.

The use of a closed boiler house for purposes of forced draft, though largely used on board ship, is rarely, if ever, used on land, and need not be further referred to than to say that it is inferior to the closed ash-pit system.

With all systems of draught, the gases escape from the boiler at a high temperature, though some types of boiler extract more heat from them than do others. With natural draught, as we have seen, the temperature of the escaping gases must not be less than 300° F., but any excess above this is practically waste. With mechanical draught the heat in the gases discharged into the atmosphere serves no useful purpose.

Now, the heat represented by the excess temperature may be utilised either to heat the feed water or to heat the air used for combustion. Much attention has been given to the subject, and most successful results have been attained on both principles, and, whatever system of draught be employed, a thoroughly reliable apparatus exists for utilising the waste heat.

It is noteworthy that if the air be heated instead of the water, some means should be adopted to avoid the evils of feeding the boilers with cold water.

With natural draught the heat is always utilised to heat the feed water, the apparatus being known as an Economiser. The invention is due to Edward Green, and, although there are others in the market, the Green economiser is the one employed in the majority of cases.

The apparatus is, in effect, a tubular boiler heated by the gases. It consists of a number of tubes, 9 feet long and $4\frac{9}{16}$ inches diameter, made of a special mixture of cast iron having great tensile strength. All tubes are cast vertically, and each is tested to a pressure of 650 lbs. per square inch.

These are made up into sections of various widths, usually eight or ten tubes wide, connected together by means of 'boxes' at top and bottom, the ends of the tubes being forced into them by hydraulic pressure, the surfaces in contact having been turned and bored so as to make a secure metal joint.

The tubes are set vertically in the flue, dampers being arranged to deflect the gases on to them. A reserve flue, through which the gases can pass directly to the chimney, is always provided.

The various sections are connected together in parallel at top and bottom by means of horizontal pipes. The sections are usually in batches of about a dozen, the horizontal pipes of the individual batches being connected together by means of U-shaped copper pipes to allow for expansion.

The feed water enters the economisers at the bottom, and is fed in at the cool (*i.e.*, the chimney) end, leaving the apparatus at the hot (*i.e.*, the boiler) end from the top pipe, having risen through the tubes in parallel streams.

Relief valves are fitted to each batch of tubes to avoid excess of pressure.

In order to keep the tubes clean and free from soot or dust, each is fitted with a scraper with chilled edges; these scrapers are carried by bars which are caused to traverse slowly up and down by means of chains, so that the scrapers pass from end to end of the tubes.

The details of the apparatus have received much attention, and provision is made for easy access to all parts for cleaning. The whole of the mechanism is of great strength and durability, and the cost of maintenance is exceedingly small.

If the water entering the economiser be colder than 90° F., it will cause condensation of moisture on the surface of the lower portion of the tubes, a thick hard cake of soot will form, and in time the tubes will corrode. The best way to overcome this difficulty, when surface condensers are not in use, is to warm the water before it reaches the economisers by means of an ordinary feed-water heater, taking the exhaust steam from auxiliary engines; or, if this cannnot be done, the damage may be confined to a small portion of the economiser, by connecting a few sections in series with the remainder of the economiser and passing the water first through them. These tubes should be fitted with special 'crab-jaw' scrapers.

The economy effected by this apparatus is very great, and may amount to as much as 25 per cent. of the fuel. The tubes can be made for any pressure at which the boilers can be worked. Though useful with all types of boiler, the economiser may be said to be a necessary adjunct to the Lancashire boiler, and, in fact, in ordinary Lancashire practice it is rarely omitted.

For estimating the size required, two rules are given by the makers, viz.: (1) four tubes for each ton of coal consumed per week of 50 or 60 hours; or (2) one tube for every indicated horsepower, no mention being made, however, of the kind of engine. Neither rule accords well with the conditions of central station work, in which the load is continuous, but very fluctuating. The number of tubes put in for this class of work is usually less than would be given by the rules, but the greater the number of tubes, in reason, the greater the economy in fuel; the number that it will pay to put in will obviously depend on the relative importance of the item of fuel in the works' costs.

The following point in the practical operation of economisers is important. As already stated, the tubes are usually so arranged that the water to be heated passes through them all in parallel. The rate at which it passes through a given tube depends on the temperature of that tube, the water travelling quickest through the coldest tube. Hence the water flows most rapidly through the end furthest from the boilers. On account of this property, it is not desirable to work several complete economisers in parallel, as, if they vary in temperature (as they almost certainly will), the bulk of the water will pass through the cold one. If possible, therefore, one economiser should be assigned to a given group of boilers. For the same reason, each economiser should, preferably, have its own feed pump.

Turning from the representative apparatus just described, which is used with natural draught, we pass on to the case of induced draught. Though there is nothing to prevent a Green's economiser being used in this case, it is more usual to adopt the expedient of utilising the heat to raise the temperature of the air used for causing combustion.

The best known system, and one adopted in several central stations, is that known as Ellis and Eaves. It has been chiefly applied to boilers of the marine type, but it is not necessarily confined to these. The gases on their way to the fan are made to traverse a flue filled with horizontal tubes, through the interior of which the air for combustion is drawn. It is thus heated to a high temperature before it enters the furnace. By means of suitable valves, the heated air can be admitted under the grate when desired.

The advantages of heating the air are, first, the raising of the average temperature of the furnace, thus increasing the rate of evaporation; secondly, the more ready combination of the gases with the oxygen of the air, less excess of air being therefore required. By diminishing the amount of air that has to be admitted, the temperature of the furnace is still further raised, as there is less air to heat and less heat is carried away; the smaller quantity of air required means a diminished speed, so that the hot gases remain longer in contact with the heating surfaces. The stresses on the

boiler are diminished by the absence of cold air impinging on the plates. Another advantage is that there is practically an entire absence of smoke.

The rate of combustion attainable by this system is very high, as much as from 45 lbs. to 60 lbs. of coal per square foot of grate surface having been successfully burnt.

In some cases the tubes are placed vertically instead of horizontally, while a further development of the system consists in surrounding the boiler with two shells, one outside the other. The waste gases pass through the space next the boiler, being caused to travel in a spiral path by means of helical partitions, while the cold air enters through the outer space, being similarly guided in a spiral direction. The object of this arrangement is, of course, to utilise the waste heat to the utmost, and, by surrounding the boiler shell with heated gases, to prevent radiation of heat from it, as also to diminish the stresses on it, due to the inequality of temperature in its different parts. Though theoretically excellent, the helical system has great practical drawbacks, not the least being the difficulty of access to the boiler for inspection and repair.

The Ellis and Eaves system is in use in several central stations, and is well spoken of, the chief objections to it being the practical impossibility of fitting mechanical stokers, while a considerable amount of skill is required for hand stoking, and the fact that with high rates of combustion there is a tendency for fine portions of the coal to be drawn into the tubes.

With forced draught, the best known system of economising heat is Howden's, whereby, as in the Ellis and Eaves, which is largely founded on the Howden system, the waste gases are used to heat the air. The waste gases in this case are taken through a number of vertical tubes fixed in a chamber through which the air from the fan is forced, its temperature being raised to the extent of from 150° to 170° F. The air is admitted both above and below the grate, valves being provided to adjust the supply. This system does not require a closed ash-pit.

Among the advantages claimed for this system are: (1) high rate of evaporation and consequent saving in floor space for a given evaporative capacity; (2) economy of feed; (3) possibility of burning inferior coal; (4) diminished wear and tear of boilers. It will thus be seen that the advantages are similar to those of the Ellis and Eaves system, while the older Howden system has the additional advantages due to using forced draught instead of induced, which, as already explained, consist in the smaller volume of a given mass of air and the operation of the fans in cold air.

Experience shows that, contrary to what one would expect, the claim that the wear and tear of the boiler is diminished is sustained.

The Howden system is very widely used at sea, and the results attained appear to be most successful.

CHAPTER XI.

METHODS OF FIRING BOILERS.

Boilers may be fired with solid, liquid, or gaseous fuel. The first is, of course, the commonest; the second is usually employed only as an auxiliary in this country, though in America it is extensively used; while the third, though but little, if at all, used for central station work, is likely to receive a considerable amount of attention in the near future.

Of the three classes of fuel, only the first requires stoking. This may be effected either by hand or by mechanical means.

Hand stoking requires considerable experience on the part of the stoker, as judgment has to be exercised in the burning of different classes of coal. There are various methods of hand firing, the commonest, perhaps, being the sprinkling system, in which the fuel is spread evenly over the whole grate. Another is the coking system, the coal in this case being placed on a dead plate, *i.e.*, a portion of the grate through which the air cannot pass; it is there distilled, the volatile matter passing along the furnace and burning, while the coke which remains on the dead plate is subsequently pushed forward and itself burnt on the grate proper. A third method consists in throwing alternate charges on opposite sides of the grate.

Mechanical stokers are many, but they all fall into two main divisions, viz., coking and sprinkling. It would be tedious to describe the various machines, but a few representative ones may be referred to.

The earliest coking stoker was the chain grate, and this has recently been revived and improved by the Babcock and Wilcox Co. It is only adapted to externally fired boilers.

The fire-bars are formed of a number of cast iron links, forming an endless chain, which passes over a drum at each end. The front drum is revolved by power, and causes the whole grate to travel slowly onwards. The fuel is admitted at the front, the thickness of the layer being regulated by an adjustable door; as it passes forward it is gradually consumed, and the residue falls over the drum at the back into the ash-pit.

This stoker possesses several important advantages. It enables very long fire-bars to be used, thus securing a large grate area and consequent

reduction of the amount of fuel that has to be burnt per square foot; it is so arranged that hand firing can be resorted to, if desired; and, finally, its construction is such that the whole stoker is mounted on wheels and can be run out for inspection and repair.

The coking stoker that has probably been the most widely used is the Vicars. It is generally applied to internally fired boilers.

The coal, which is stored in a hopper, falls into two cylinders, one on each side of the grate, and is forced forward by means of pistons on to the dead plate where coking takes place. The fire-bars are made to reciprocate, and are divided into two sets, alternate bars forming a set. Both sets move forward together; one is then withdrawn, the other standing still; then the other is withdrawn, and both again move forward together. The effect of these movements is to carry the fuel forward and then to break up the clinker. Steam jets are employed between the fire-bars to keep them cool.

The mechanism is so arranged that a number of separate adjustments can be made and the amount of coal and travel of fire-bars independently adjusted, while the speed of the machine as a whole can be varied.

This stoker differs from many others in that it is possible to greatly force the boilers to which it is fitted, though at the expense of the fire-bars, which have to be short. It is reliable, strong, and very efficacious in preventing smoke, but the repairs are heavy. It is not adapted for burning coal containing much sulphur or dirt, as solid masses of clinker are then formed which clog the bars and stop the stokers.

Much doubt appears to exist as to the amount of power required to drive plant of this kind, and the makers have as little definite knowledge on the subject as their customers. This, no doubt, arises from small steam engines being employed for the purpose, and the amount of power they are wasting is a matter of guesswork. The following measurements made by the Author may, therefore, be of interest:

In the first case, Vicars stokers fitted to a battery of six 30 feet by 8 feet Lancashire boilers were run from a common shaft running at about twenty-eight revolutions per minute by means of a motor having a speed of about five hundred revolutions per minute, driving by means of Hans Renold driving chains, through a countershaft.

When running light, driving shafting and gearing only, the horsepower absorbed by the motor was 1·68. When five stokers were at work the horsepower was 2·49, or half a horsepower per stoker.

The effect of varying the rate of stoking with the five running was tried. At the minimum rate, the horsepower taken was 1·73 H.P., and at the maximum 2·9 H.P.

The second case was that of a battery of twelve Lancashire boilers of the same size as the last named, but the motor drove the common shaft by means

of a worm and worm wheel. The shaft ran at about twenty revolutions per minute, and the motor at about eight hundred revolutions per minute.

The horsepower taken to run the shaft and gearing light was 4·55, and, with ten stokers at work, 4·85, or slightly under half a horsepower per stoker. The smallness of the additional power required to run the stokers above that for the shaft alone is very striking, and may probably be explained by the fact that the stokers break step and do not therefore take power simultaneously.

In order to test this point, observations were made over a period of thirty minutes; and with eight stokers, working at a fairly heavy rate, the power was found to vary from a minimum of 4 H.P. to a maximum of 6·2, or from half to just three-quarters of a horsepower per stoker.

The power varied from 5·1 H.P. at the minimum rate of stoking to 6·32 H.P. at the maximum rate when ten stokers were at work.

Other well-known examples of coking stokers are the Hodgkinson and the Proctor, but there are many more.

Of sprinkling stokers, perhaps the most widely used is the Bennis. In this the coal falls from a hopper on to a flat plate, from which it is periodically pushed by means of a plate, worked by a cam, into a shovel carried by a lever. The lever is actuated by a tappet, and forces the shovel against a spring, which, on being released, causes the shovel to throw the coal into the furnace. Four different amounts of travel are given in succession to the lever, and the coal is thus flung to four different distances, the maximum being six feet, and the space covered by a single throw being eighteen inches long. In this manner a close imitation of hand firing by sprinkling is obtained.

The fire-bars are given a reciprocating motion to carry the fuel forward, and one in eight is displaced at a time in order to break up the clinker.

Among other sprinkling stokers, the Proctor is one that has met with a good deal of favour.

Both classes of stoker have their advocates, but the coking class appears to be the one found most satisfactory in practice.

It is most difficult to arrive at any conclusion as to which is the best stoker individually, most contradictory accounts being given of their performance. No doubt this arises largely from the varying nature of the work they are set to do. Under the conditions of central station practice, it seems certain that with all machines the repairs are considerable, and, when the boilers are forced, very heavy.

It will be well to examine what are the advantages of mechanical stoking over hand firing. Some of the advantages are undeniable. In the first place, the continuous feeding of fuel, as against the intermittent charging by hand firing, secures uniform and more perfect combustion of the fuel; while the fact that the fire-doors have not to be opened relieves the boiler from the severe stresses set up by the admission of cold air, besides avoiding

the waste of heat consequent on the introduction of an excess of cold air. Again, a lower grade of coal can be efficiently burnt than is possible with hand firing, though it must be borne in mind that a lower priced coal is not necessarily cheaper; it depends entirely on the calorific value of the two fuels. The practical elimination of smoke is of considerable moment, especially when the central station is within a town, while the cleanliness compared with hand firing is of value.

When we come to compare the cost of the two methods, we are not on nearly such sure ground. Leaving out of consideration the saving due to the advantages already enumerated, and comparing only the cost of the actual stoking, we have on the one side the wages of the firemen and on the other the interest on the first cost of the stoking machine, its depreciation and the cost of its upkeep, together with the wages of such men as are indispensable, even though the whole of the work be done automatically.

Obviously, with one boiler, the cost of mechanical stoking is greatly in excess of hand firing, but, as the number of boilers increases, the cost per boiler diminishes, and, with large batteries, the position is almost certainly reversed, though it is doubtful whether the saving is as great as is apt to be supposed. Even granting, however, that the cost were the same in both cases, the balance would be turned in favour of mechanical stokers, because the more the labour element can be eliminated, the less is the danger from disputes, carelessness, and incompetence.

Taking into account, however, the other advantages, *i.e.*, the cheaper fuel, the better combustion, the saving of wear and tear of the boilers, increased cleanliness and absence of smoke, it may be said, without any hesitation, that, for all stations, except those of smallest size, a substantial saving can be effected by the use of mechanical stokers.

Before leaving the subject of the burning of solid fuel, reference must be made to the down-draught furnace. With this system, two grates are provided, one above the other. The whole of the fuel is fed on to the upper one, and the lower is used merely to burn such fuel as falls from the first. The fire-bars of the upper grate are tubular, and a constant circulation of water from the boiler is kept up through them. The draught is directed downwards, the bulk of the air being admitted above the fuel on the grate. About 90 per cent. of the combustion takes place on the upper grate.

The advantages of this system are that the boilers can be greatly forced without causing smoke, while a high degree of perfection of combustion is attained, since whatever fuel escapes burning on the upper grate is consumed on the lower, this result being attained without costly plant or complicated mechanism, and, finally, very small and low grade coal can be satisfactorily burnt. The drawbacks to be noticed are, the impossibility of using mechanical stokers, the high draught necessary, the need for exceptionally pure water for the tubular fire-bars, and their liability to mechanical injury.

Liquid fuel usually consists of the residue from the distillation of petroleum, though creosote oil and gas tar are sometimes employed. The combustion arrangements are very simple, the oil being injected into the combustion chamber by means either of compressed air or a steam jet, and directed on to an incandescent mass of brickwork. The best known system is Holden's, wherein the burners have two apertures. The liquid enters through an annular nozzle surrounding another, through which the steam is blown, while air passes in by a central nozzle, oil, steam, and air being intermixed before escaping into the combustion chamber. A number of additional small jets of steam are caused to play upon the stream as it enters the chamber, thus converting it into a fine spray mixed with air.

Though chiefly applied to locomotives, liquid fuel has been used in central station work as an auxiliary to ordinary fuel. It possesses the advantage of enabling the boilers to be forced conveniently at a moment's notice, and that without causing smoke.

We now pass on to consider the firing of boilers by means of gas. This is only just being introduced for central station work, but it has been employed for other purposes for many years.

The gas used most frequently in this country is the waste gas from blast furnaces, but there are not likely to be many cases in which this will be available for central stations. Ordinary coal gas may be employed, but at ordinary prices this is expensive; that most generally available, however, is producer gas, generated at the station.

Producers are of various kinds, and there are many varieties differing in matters of detail in their construction. The class most suitable for central station work is that in which the fuèl is gasified by the combustion of a certain proportion, steam and air being introduced for the purpose.

For the purpose of describing the process, a recent form is shown in fig. 17. The fuel rests on a cast iron fire grate, consisting of a grid, sloping at a sharp angle on the two sides of a central line. A steam blast is introduced beneath this grate, and passes upwards through the fuel. The office of the steam is partly to produce the draught necessary for combustion and partly to combine with the gas evolved. Combustion takes place on the grate, and the heat conducted and radiated distils the coal above, the gases being drawn off from the top.

The producer is rendered gas-tight by means of the water seal at the base. By this arrangement, the producer can be worked continuously, the clinker being removed from the water bath.

Pokering holes are provided at the top of the producer through which the attendant introduces an iron bar and breaks up the clinker from time to time. The fuel is introduced at the top, a measuring hopper being filled and then suddenly emptied into the producer. This charging is effected at intervals by hand.

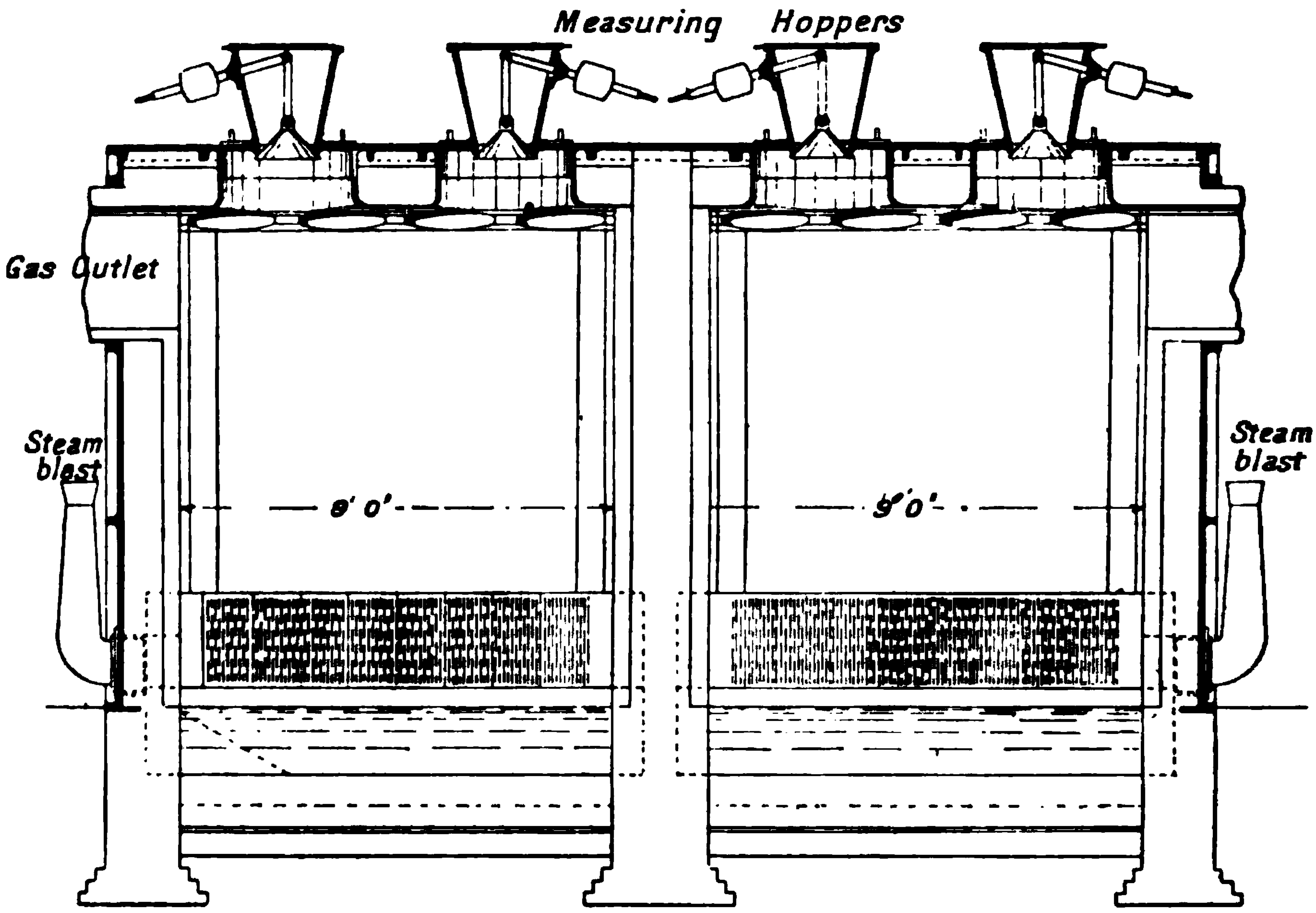


Fig. 17A.—Gas Producer (Longitudinal Section).

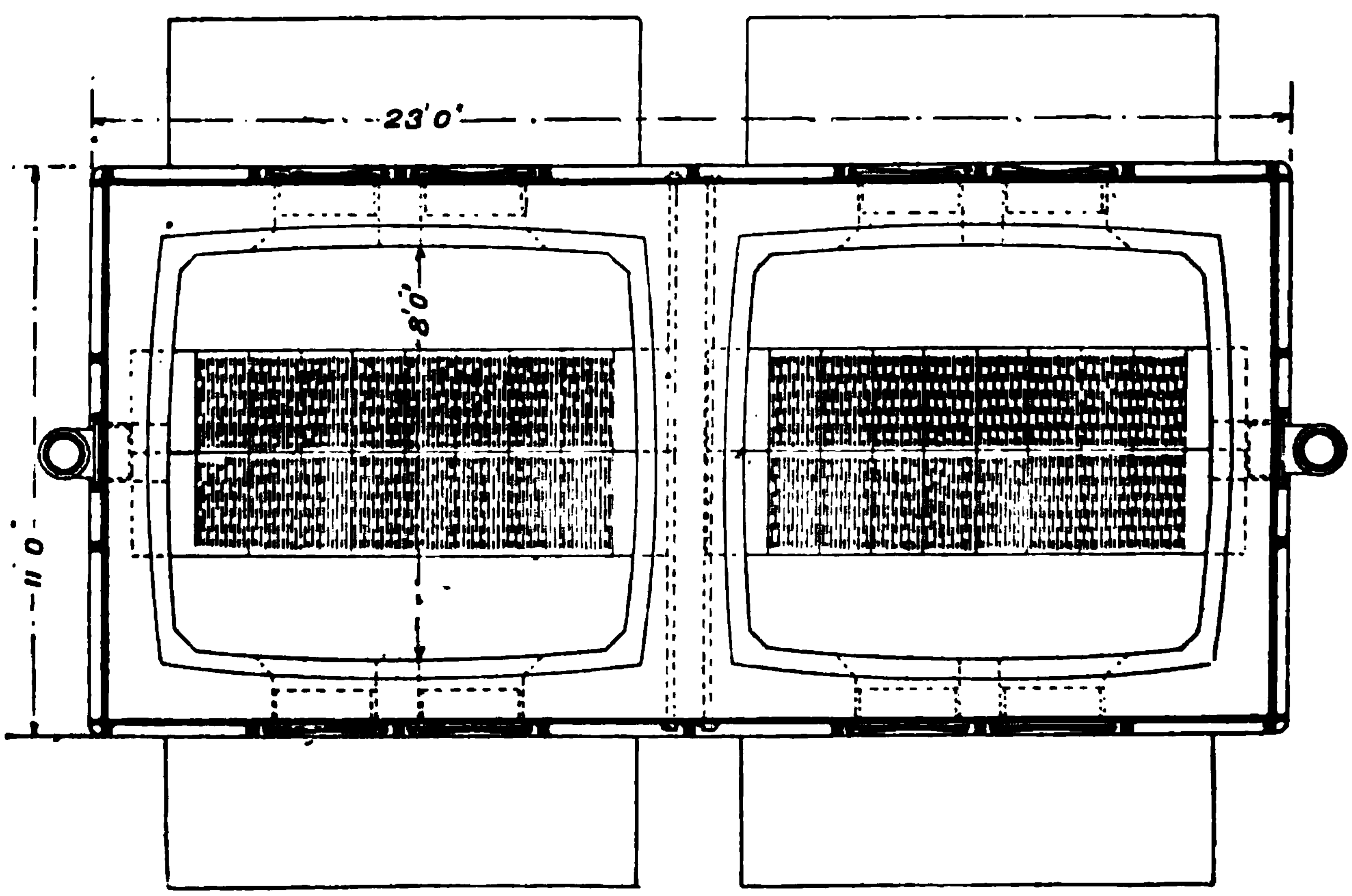


Fig. 17B.—Gas Producer (Sectional Plan).

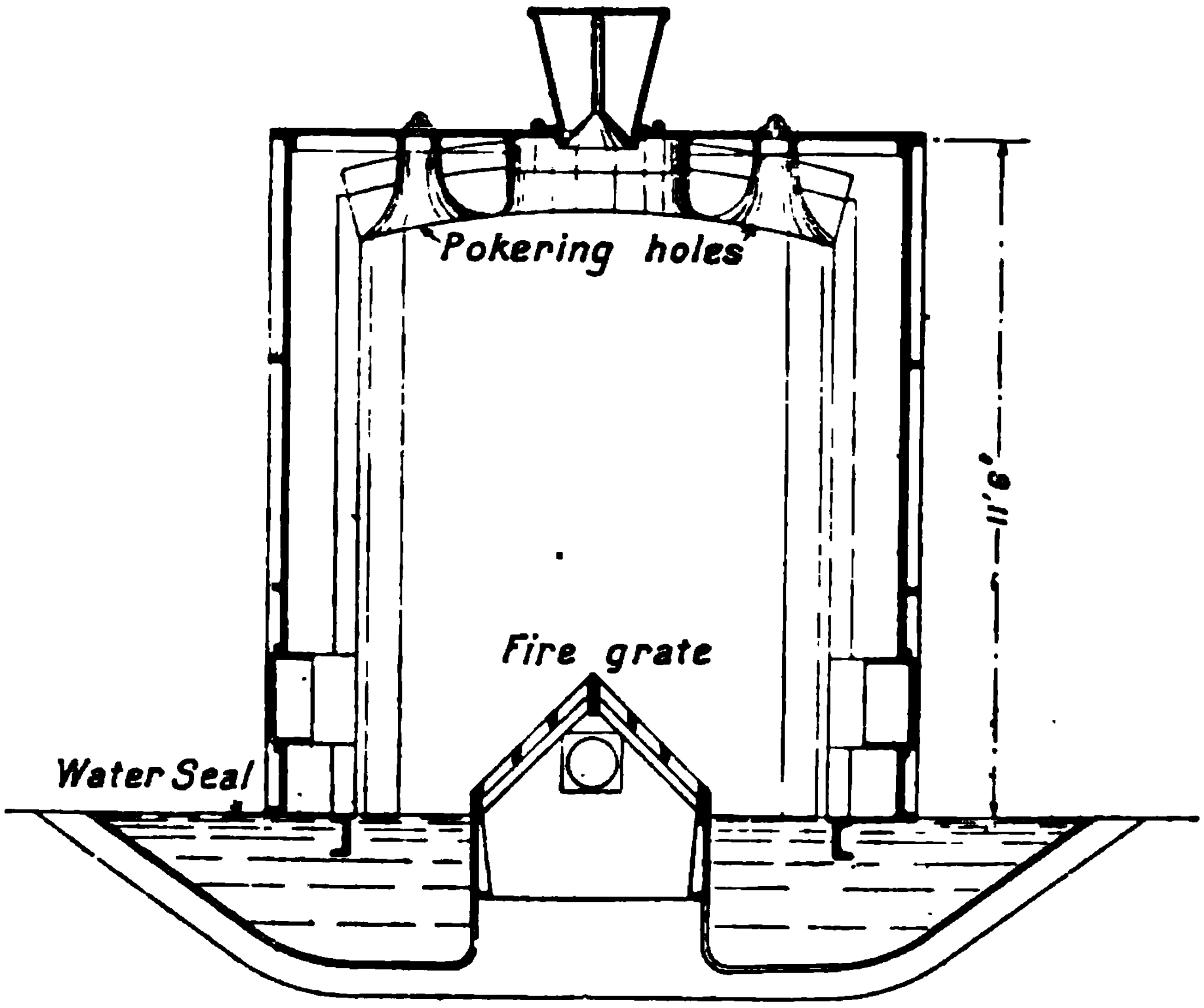


FIG. 17C.—Gas Producer (Cross Section).

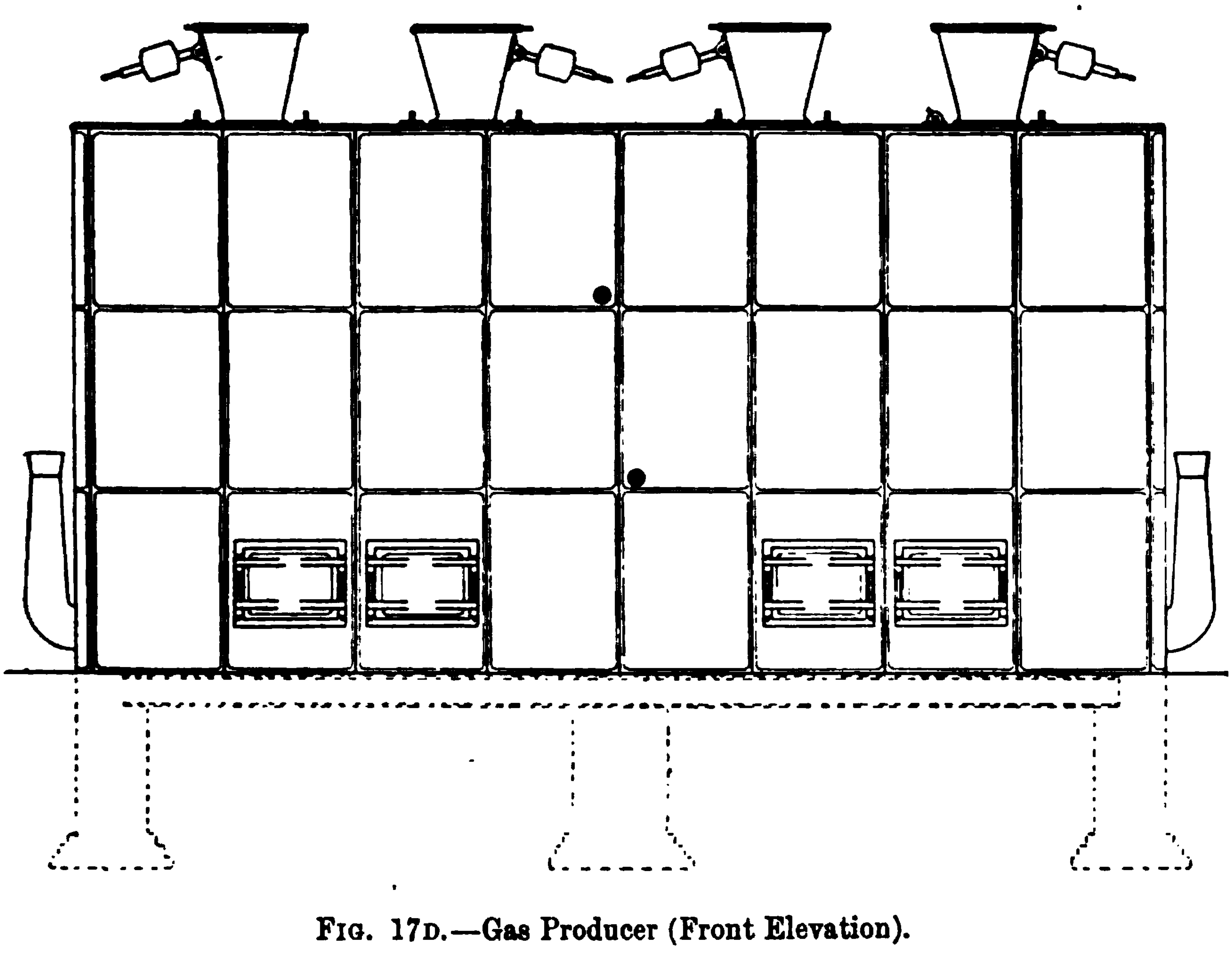


FIG. 17D.—Gas Producer (Front Elevation).

The composition of the resulting gas depends in large measure on the proportion of steam introduced, and this may vary between very wide limits.

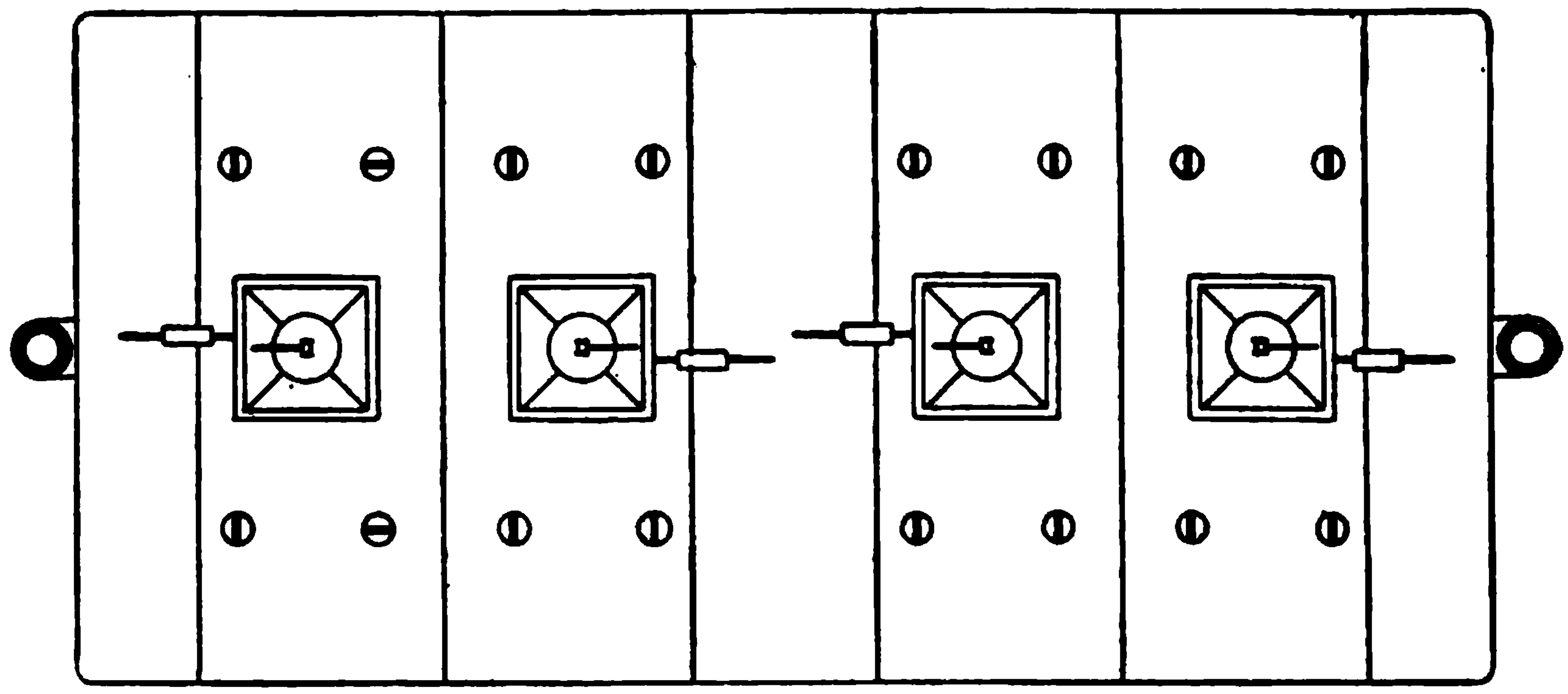


Fig. 17E.—Gas Producer (Plan).

The gas most suitable for firing boilers, without regard to other considerations, is produced when a moderate amount only of steam is used. The analysis

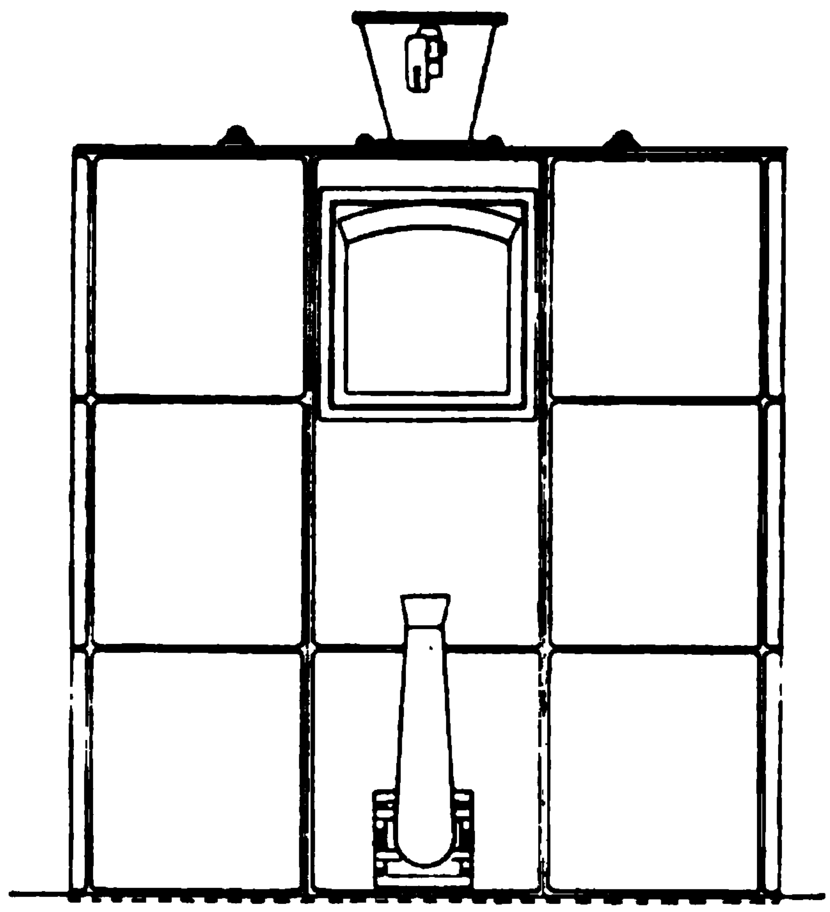


Fig. 17F.—Gas Producer (Side Elevation).

of the gas from two producers supplied with a moderate amount of steam is given below; the tests are the mean of a daily analysis taken over several months, and are therefore representative.

Constituents of Gas.	Siemens Producer.	Duff's Producer.
Carbon dioxide,	4·8 per cent.	4·0 per cent.
Carbon monoxide,	22·2 ,,	26·8 ,,
Hydrogen,	4·8 ,,	13·4 ,,
Carburetted hydrogen,	4·3 ,,	4·4 ,,
Nitrogen,	63·9 ,,	51·4 ,,

It will be observed that a considerable quantity of nitrogen passes through the producers and serves no useful purpose. If, however, hydrogen be supplied, it will combine with the nitrogen to form ammonia; and this is often done, the gas being obtained by the introduction of a very large quantity of steam, as much as a ton for every ton of fuel gasified.

Plant laid down with a view to obtaining sulphate of ammonia as a bye-product is known as 'recovery plant,' and exceedingly satisfactory results have been obtained with continuously working apparatus; so profitable, indeed, is the process, that it has been stated that the sale of the ammonia has produced as much money as was paid for the fuel, so that the gas was obtained for nothing.

It will be well to examine carefully what are the advantages of gas firing and what are the prospects of reducing the cost of electrical energy by the use of a recovery plant.

In the first place, it is to be observed that solid fuel has in fact to be turned into gas in any case for combustion to take place, and, whereas in ordinary stoking the gas production and combustion take place in one and the same furnace, in gas firing the solid fuel is gasified in a separate chamber. Now, it is well known that careful regulation of the admission of air, both as to its volume and its proper admixture with the gases, is necessary in order to secure complete and efficient combustion, and it seems obvious that this can be more easily secured when the volume of gas introduced is under absolute control, and the gas can be thoroughly mixed with air. It therefore seems indisputable that more perfect combustion can be attained by gas firing.

Secondly, since the processes of vaporising and distilling absorb heat, the temperature attained in the combustion chamber is higher when these processes take place in a separate chamber. This is further assisted by the possibility of so regulating the admission of air that only just enough for combustion is introduced, and the amount of inert gas that has to be heated is thus reduced to a minimum.

The cleanliness of the combustion, the uniformity of the temperature, and the absence of necessity for admitting cold air when stoking, are very great advantages. They tend to prolong the life of the boilers and to greatly diminish the cost of attention and maintenance.

The ease with which the supply can be varied is such that the labour required for the actual combustion is practically *nil*, and the rate of evaporation can be varied instantaneously at will, the boilers being forced to their utmost by the mere opening of a valve.

Against this saving of labour must be set the cost of attendance on the producers, men having to charge them and keep the clinker stirred. As this cannot well be done by mechanical means, the number of men will probably be greater than when solid fuel with mechanical stokers is

employed, but less than with hand firing, while practically no skill is required.

The wear and tear on the producers is practically negligible, and a fire-grate will last for many years; hence the saving in fire-bars and repairs to mechanical stokers is very large.

The floor space taken up by the producers is considerable, and this must be taken into account when considering their use. The capital cost also is substantial, but against this must be set the saving through having no mechanical stokers. The cost of a producer, including setting, may be taken at about 4s. per pound of coal gasified per hour.

Gas firing secures absolute immunity from the production of smoke, and allows of low grade coals being employed.

It is obvious that, inasmuch as some of the coal has to be consumed to generate the heat necessary to produce the gas, and inasmuch as the gas producer radiates heat, as also do the pipes conveying the gas to the boilers, a portion of the heat obtainable from the fuel is lost; but, on the other hand, the combustion under the boiler being more perfect, the net result is probably not very different to that obtained with ordinary firing.

A producer can be shut down and started up very rapidly; hence the radiation losses during hours of light load can be greatly reduced, and periods of sudden demand can be satisfactorily met.

To sum up, it may be said that the number of pounds of water evaporated per pound of fuel burnt is about the same whether gas or ordinary firing be used, the ground space occupied by the plant is much greater with gas firing, and the initial capital cost is somewhat greater than with solid fuel; but the cost of running is less so far as attendance is concerned, the cost of upkeep of the boilers is very much less, the standing losses are diminished, the convenience is very great, and the boilers can be forced with ease. On the whole, where land is cheap, it would seem that the balance of advantages is in favour of gas firing. If it be adopted, Water-tube boilers should be employed, this form being much better adapted to the system than the Lancashire type, while many of the drawbacks of Water-tube boilers disappear when fired with gas. It should be borne in mind that a certain amount of gas escapes during charging and pokering, so that there is a possibility that nuisance may arise on this score.

So far we have considered the advantages accruing from the mere production of the gas outside the combustion chamber. What are the further advantages introduced by putting down a recovery plant?

It will be necessary to describe briefly the process employed, and for this the Mond system, which is one of the most modern, may be selected.

The producer consists of two concentric cylindrical wrought iron shells, the outer being lined with firebrick for part of its height. The top is arched and lined with firebrick, and the bottom slopes towards the grate.

A water seal is used, as in the producer previously described. The grate is formed by a cylindrical cast iron ring, which serves to support the upper end of the fire-bars that slope downwards to another ring, which supports the opposite ends. The fuel passes from the feeding hopper into a bell-shaped casting, round which the hot producer gas is passing, and distillation begins, the products passing downwards through the heated fuel beneath, the tar being thus got rid of. The mixture of steam and air passes between the two shells, becoming heated in so doing, and at the same time cooling the inner shell, the radiation from which is thus utilised.

The gas is drawn off from the upper part of the producer and taken straight to a regenerator, consisting of concentric wrought iron tubes, through the inner ones of which it passes, while the air and gas pass between the tubes. It next passes through a washer comprising a wrought iron vessel in which a large quantity of fine spray is constantly thrown up by mechanical means. In this way the gas becomes impregnated with aqueous vapour at a temperature of about 90° C., but it is not saturated.

The gas thus cleaned and moistened is next taken through an acid tower, in which it passes through a stream of acid liquor containing about four per cent. of free sulphuric acid, the rest of the acid being combined with ammonia as sulphate. In this tower the gas gives up its ammonia.

From the top of the acid tower the gas is passed through a vessel in which it is cooled by means of cold water, and a considerable portion of the steam it contains is condensed, the water leaving the vessel at a high temperature, and being subsequently used to warm the air before it enters the producer and impregnate it with steam.

The gas is now available for use in firing boilers, or it may be used in gas engines, as it is clean and cool.

The air required by the producer is forced in by means of a blower, which maintains a pressure within the whole apparatus.

The sulphate of ammonia is first neutralised and then evaporated, and the crystals dried, after which the sulphate is ready for sale.

In some tests made by Mr H. A. Humphrey, coal, consisting of Nottingham slack, costing 6s. 2d. per ton, was used. It was found that for every ton of fuel gasified, about 2½ tons of steam and 3 tons of air were blown through the grate, the temperature of the mixture being 250° C. One ton of the steam was derived from the system of regeneration, while 1½ tons had to be added, being taken from the exhaust of engines. More than half a ton of steam was decomposed in the producer, and nearly 4½ tons of gas formed from 1 ton of coal, or about 160,000 cubic feet at ordinary temperature. One ton of coal produced a little over 93 lbs. of ammonium sulphate, of which the selling price was £7. 4s. 6d. per ton, or, for the 93 lbs., about 6s. 2d., *i.e.*, exactly the cost of the original fuel. This does not take into account the cost of the additional coal necessary for producing

the steam, which amounts to about 0·15 ton additional per ton of fuel gasified.

The composition of the gas is as follows:—

Hydrogen,	24·8 per cent.
Marsh gas,	2·3 ,,
Carbon monoxide,	13·2 ,,
Carbon dioxide,	12·9 ,,
Nitrogen,	46·8 ,,

Its calorific value is about 81 per cent. of that of the original fuel.

At first sight, it would seem that there need be no hesitation in the matter, and that all boilers should be fired with gas, produced in conjunction with a recovery plant, since the cost of the fuel is, as it were, wiped out. A little consideration will show, however, that the capital cost of providing the recovery plant is high; and although, in a chemical works where it can be operated continuously, this may not be serious, yet, in the intermittent work of a central station, this cost may render the benefits practically nugatory, when taken in conjunction with the cost of attendance on the recovery plant, the expert supervision required (for the business of a gasworks is practically added to that of an electric generating station), the large floor space taken up, and the difficulties introduced into the working of the recovery plant by the fluctuating gas supply. Some of the difficulties could, no doubt, be overcome by storage in a gasholder; but this again cannot be obtained without capital expenditure on the plant and land.

There are other considerations, moreover, which, though less obvious, are none the less weighty, in diminishing the apparent saving effected. Thus, the diminished heating value of the gas, as compared with that produced without recovery plant, requires greater boiler capacity for the same amount of water evaporated; while the large quantity of steam required, although account has been taken of the fuel necessary to evaporate it, involves additional cost for engines, since a large proportion of those at work must be run non-condensing to provide the exhaust steam.

To sum up the case of gas firing with recovery plant, compared with gas firing without, it may be said that, so far as the actual firing is concerned, the gas from an ordinary producer is the better, and requires the less capital expenditure on boilers and engines, while the absence of complication is greatly in its favour; on the other hand, the recovery plant enables a valuable bye-product to be obtained, which may or may not yield a profit on the capital invested to produce it under the conditions of a central station. Actual practical experience alone can show how these conditions will influence the result, and it is satisfactory to know that the system is at present being tried.

It may be well to point out that if the gas be employed for internal

combustion engines, instead of for firing boilers, the economy as against steam engines is enormous; and if this class of engine can be adapted to the requirements of central station work, as there appears good ground for hope that it may be, boilers will disappear altogether. Though this contingency belongs to the future, it should not be lost sight of, and it supplies an argument in favour of gas firing with recovery plant, as the gas would be available for gas engines if it were decided to adopt them for extensions.

CHAPTER XII.

COAL HANDLING, WEIGHING, AND STORING.

SINCE coal is the immediate source of most of the energy distributed electrically in Great Britain, the cost of this commodity is one of the principal items in costs of production.

The price charged is made up of three principal parts, viz., (1) the prime cost of the coal in the pit, depending on mining royalties, etc.; (2) the cost of getting the coal and putting it on the bank at the pit's mouth; and (3) the cost of carrying and handling it, from the time it is brought to the surface to the time it reaches the fire-grate where it is burnt.

Obviously the third is the only item which the Central Station Engineer can control. Even this he can only do in part, but he can affect the amount materially. This may be done in several ways; primarily by the choice of the site for the generating station, and then by the means adopted for receiving, storing, and distributing the coal and for feeding the furnaces.

It is most desirable that the site chosen should be one which admits of coal being brought either by water or by rail at will. If by water, a navigable river gives a much wider range of choice of contractors than does a canal. If it be a canal that is available, it may happen that only one or two collieries are situated on its banks, and sufficient competition cannot then be obtained. In the case of a railway, practically unlimited competition between contractors can be had, but the Railway Co. may be extortionate. For convenience in handling, a railway is greatly to be preferred, since trucks are much more manageable than boats.

Every station ought to store sufficient coal to last for a week and for as much longer a period as can be arranged for, certainly up to three months. The effects of a coal strike would be appalling in the case of a large station supplying lamps, motors, and trams; the damage ensuing from stoppage of supply must be appraised and weighed against the cost of the necessary land, on the price of which will depend the amount that can be stored.

The difficulties in the way of storing coal are considerable, the chief being its liability to spontaneous combustion and deterioration in quality

with keeping. As regards the latter, it is found that when coal is exposed to the weather it depreciates in value, its calorific value becoming less and its coking qualities greatly altered and sometimes entirely lost. If, however, the coal be kept dry, the deteriorating action progresses very slowly—a fact which points to the necessity of keeping it under cover.

Coal, when exposed, has the property of absorbing air, more being absorbed the higher the temperature; the extent of this action varies with the kind of coal.

The spontaneous combustion of coal, especially when stored in large masses, is by no means an uncommon occurrence, but its cause is somewhat obscure. There appear to be two principal causes, either or both of which may be operative.

The first is the oxidation of the sulphur compounds contained in the coal, the most important being pyrites. This substance exists in different physical forms, some of which are more readily attacked than others; some will oxidise by mere exposure to the air, while others require heat to set up the action. In all cases, moisture promotes the oxidation, even if it be not essential to it.

The second cause of spontaneous combustion is the absorption and condensation of the oxygen from the air in the pores of the coal, which, as already stated, has the power of absorbing this gas from the air. Some coals have this property in a more marked degree than others; while, in the case of the closely allied substance—charcoal—the action is so pronounced that it frequently ignites from this cause. The more porous the coal, the more readily will it absorb oxygen, and absorption is further favoured if the coal be in a fine state of division.

Both the oxidation of the pyrites and the absorption of air by the coal are accompanied by the evolution of heat and consequent rise in temperature; the more the heat is confined, the higher is the temperature attained. Hence the larger the mass stored, the greater is the tendency to spontaneous combustion.

Observation shows that moisture has much to do with the phenomenon. In all probability the first action is for the pyrites to oxidise, being helped thereto by the presence of the moisture, the heat thus produced promotes the direct oxidation of the coal rendered possible by the absorbed oxygen; this then ignites, and causes destructive distillation of the coal in the immediate neighbourhood, the products of the distillation take fire, and the whole mass bursts into flame.

Spontaneous combustion has been known to take place in all kinds of coal, but never with patent fuel, *i.e.*, briquettes. No doubt this is because, during the process of manufacture, the bulk of the moisture is expelled, so reducing the tendency to oxidation of the pyrites; while, whatever tendency to oxidation by air absorbed by the coal before being made into briquettes

there may be, such oxidation is promoted and completed during the manufacture, and after the blocks are completed they have but little porosity.

As regards the length of time that may be expected to elapse before coal is liable to take fire, it has been found by observations made on ships—marine work being that in which this question is of greatest importance—that ignition in no case took place in less than 37 days, while, in one case, as long a period as 190 days elapsed before a fire was found; the average time was 60 days.

The above considerations point to the necessity of observing the following points in order to minimise the risk of spontaneous combustion taking place :—(1) The coal should be as dry as possible when stored. (2) It should be stored under cover, and should be protected from the access of moisture from any source. (3) It should be in as large lumps as possible, and fine coal or dust should be avoided. (4) The store should be subdivided with partitions so constructed that they interpose an air space between the heaps that they separate, thus keeping the masses of coal as small as possible, and providing a cooling surface for them, while, at the same time, isolating the damage if a fire does take place. (5) No ventilation should be provided through the coal, as it is important to exclude air from the interior of the heap; but the surface of the coal should be well ventilated, so as to remove any gases that may be given off and to assist in keeping the mass cool. (6) Thermometers should be provided at suitable points so that the temperature may be watched. (7) The store should be in a cool place and well away from boilers. (8) In using coal from the store, care should be taken to remove it systematically, and to thoroughly clear out each partition, in this manner ensuring that none of the coal remains in the store for an undue length of time. (9) The store should be entirely emptied as often as possible, certainly once a year.

The danger of explosion must not be overlooked. The liability to this arises from the presence of marsh gas within the coal, often under appreciable pressure. This escapes when the coal is broken. Hence the likelihood of explosion is greater soon after the coal is placed in the store, as it is in the action of handling it that it is broken and the gas set free. Efficient surface ventilation is sufficient to guard against this danger.

We have now to consider the question of handling the coal.

The complete problem involved in the expression 'coal-handling' in connection with central station work comprises the reception of the coal at one or more definite points, its distribution over a considerable area for storage, and then its delivery at a number of fixed points of consumption.

It will be seen that there are thus several distinct processes :—(1) the discharge of the barges or trucks; (2) the conveying of the coal from the

point of reception to the store; (3) the distribution from the store to the boilers. In the case of very extensive storage, there will be two intermediate stages between (2) and (3), namely, the distribution of the coal over the store and its re-collection from that store.

It may be at once said that the Author knows of no plant that will carry out the whole problem without the intervention of hand labour. That is to say, there is no mechanical device that will take coal from a fixed point, distribute it over an extended area, collect it again from that area, and deliver it at another fixed point.

The apparatus practically available may be divided broadly into elevators and conveyors. When storage is so limited in amount that a single large bunker or series of bunkers will contain the whole amount stored, these two classes of plant will suffice, but when a really large reserve is desired they are quite inadequate.

The elevation of the coal may be effected in many ways; the first thing to consider, however, is how to get the coal into the elevator. If the supply comes by water, grabs may be used for unloading ships; but if river or canal boats have to be dealt with, they are quite useless, as there is not sufficient depth or bulk for the grab to operate on. When delivery is by railway, the problem is much simpler, as the truck itself can readily be raised either by an inclined siding or by a lift.

With boats there is no choice but to throw the coal out by hand into the elevator, care being taken to make the height to which it has to be thrown as small as possible. A means of preventing the necessity of this preliminary hand labour is in use in Manchester. It consists in bringing the coal in ready-filled boxes holding from 25 to 30 cwt. each, the boxes being contained in a specially built boat. This method is satisfactory, but can only be adopted in special cases, while it possesses the disadvantage of materially reducing the carrying capacity of the boats.

The cost of this hand labour can be made surprisingly small by good organisation, so that it is not a serious matter; but it is undeniable that the process is a slow one, and much benefit would result from a mechanical device that would do the work.

The coal may be elevated by means of ordinary cranes, in which case each lift will comprise a considerable quantity of coal, say a couple of tons. Another method consists in having a series of buckets, each carrying a small quantity, which buckets are fixed on an endless chain—a Jacob's ladder, in fact.

Which of these two methods is preferable depends chiefly on the means used for conveying the coal when lifted; but, on their merits, it may be pointed out that the former method requires a motor of large power, used intermittently, to drive it, while the latter requires a much smaller motor,

running continuously, and, therefore, from this point of view the Jacob's ladder is to be preferred.

In order to convey the coal, a similar broad division in the species of plant available is to be noted. The material may be moved in big masses by means of travelling cranes, or it may be taken in small quantities by means of a continuously running conveyor. Of the second type of plant there are many varieties.

In this case, again, the same remark applies as to the size of motor required and the time of running, but the difference between the two systems is not so great, as the continuously working conveyor, especially if the distance be great, may readily have larger frictional losses than the travelling crane, and the total amount of energy required in a given time will then be greater.

The class of crane elevators and conveyors does not present any uncommon features; it may therefore suffice to describe two examples in use at the Dickinson Street generating station of the Manchester Corporation.

In the first instance, an overhead gantry extends the whole length of the boiler house, and is fixed over the coaling floor. On the gantry runs a travelling crane driven by an 11 H.P. continuous current shunt wound motor. The motor is started from a switch fixed on the wall, and is kept running constantly in one direction. All the necessary motions for lifting and travelling, and for reversing both motions, are made mechanically by shifting belts. The coal is lifted in boxes holding from 25 cwt. to 30 cwt., and is travelled to any desired point on the coaling floor and there discharged. It is then shovelled by hand into the stoker hoppers. The whole load lifted, including box and tackle, is about 2 tons, the speed of lift is 28 feet per minute, and the speed of travel 66 feet per minute. The length of the gantry is 196 feet.

An obvious defect of this system is the shovelling of the coal by hand. This is avoided in the second instance. Here a large bunker is provided, into which the coal is dropped, whence it falls by gravity into the stoker hoppers. Over the hopper is fixed a gantry, and on this runs a travelling jib crane. Boxes of the same weight as before are lifted at a speed of 29 feet per minute, and travelled at a speed of 132 feet per minute. The extreme length of travel is 196 feet. The motor is a shunt wound continuous current motor of 11 H.P., and is started, stopped, and reversed for each motion.

Both these systems have the advantage of being simple and not liable to interruption (a duplicate is provided in each case); but they are cumbrous, and the amount of coal that can be handled by one man, who, of course, has to accompany the crane in each case, is limited.

Turning now to the class of continuously working elevators and

conveyors, it will be convenient to consider the two together, as some kinds of apparatus serve both purposes.

The first operation is to get the coal into the grab, or bucket, as the case may be. It is then lifted by a jib crane and discharged into a hopper large enough to hold one or two charges. From this hopper it may pass through a weighing machine (see below), or may go direct to the elevator, passing thereinto through a special feeder which regulates the quantity sent into the conveyor.

There are two principal forms of elevator. The first consists of a series of steel buckets fixed at equal intervals on a pair of steel chains, one on each side of the buckets, which pass over drums, one at the top, the other at the bottom. The coal passes from the feeder into the bucket, which travels upwards, and, at the top, turns over and discharges into the conveyor.

The second elevator is known as the 'gravity bucket' and is similar to the last named, but the buckets are of a different shape, pivoted, and so arranged that, whether the chains are vertical or horizontal, the bucket remains horizontal. This elevator is also used as a conveyor (see below).

The elevator discharges into a conveyor, unless it be of the gravity bucket type, in which case the elevator and conveyor are one and the same.

The conveyors chiefly in use are of the following types:—(1) Gravity bucket, (2) Push-plate, (3) Tray, (4) Belt, (5) Worm.

(1) Gravity bucket.—The chains are furnished with rollers running on rails, while the buckets are pivoted on the chains in such a manner that the centre of gravity of the coal carried is as low as possible. In order to cause the conveyor to discharge, a stop is placed which causes each bucket passing it to tip and discharge its contents into the hopper below. When sufficient coal has been discharged at this point, the stop is withdrawn and another brought into operation at the next point at which it is desired that discharge should take place. Owing to the way in which the buckets are suspended, the lower or returning half of the conveyor can be used, and ashes may thus be conveniently dealt with. Besides being capable of acting as an elevator, and going in any direction in a vertical plane, this conveyor will go round curves on a horizontal plane if the radius be not less than 15 feet. The distance to which this conveyor will carry coal is practically unlimited. It is, perhaps, the most expensive kind, but is a most excellent one. It has, however, the drawback that it requires a man to adjust the stops necessary to regulate the discharge.

(2) The Push-plate conveyor consists of a number of vertical plates drawn along a steel trough by means of chains. A series of openings in the bottom of the trough are made over the storage hopper, and the coal drops through the first opening until the pile beneath rises to the level

of the bottom of the trough. This automatically stops up the opening, and the coal in the trough is carried along over its surface and passes on to the next opening through which it falls until this opening in turn is filled up, and the process is repeated with each opening successively until the whole bunker is filled. This conveyor is thus entirely automatic in its action, and so does not require the presence of an attendant to regulate its discharge. The limiting distance to which it can transport coal is about 500 feet, and the returning portion cannot be utilised. It is the cheapest, and probably, for distances up to which it can be used, is at least as good as any.

(3) The Tray conveyor consists of a series of short trays with rectangular sides hinged together so as to form a continuous trough. It is only applicable to the case in which it is desired to convey between two fixed points, and hence it is not applicable to filling a large bunker. Like the push-plate type, it can be used up to about 500 feet. It obviously cannot be used for bringing back material with the returning portion. This conveyor will act as an elevator if the inclination do not exceed 30° to the horizontal.

(4) The Belt conveyor consists of an endless belt of American duck, treated with composition. This runs on a horizontal roller; while two inclined rollers, one on either side, cause its top surface to take a concave form. This will only, of course, transport material in one direction. The wear and tear on the belts is considerable, but the plant requires less power than any other conveyor to run it. It can be used as an elevator if it is feasible to arrange for a small inclination only. Like the gravity bucket type, the distance to which the belt will transport material is practically unlimited.

(5) The Worm conveyor comprises a worm caused to revolve in a trough having a circular bottom. The chief objection to this form is that it grinds the coal considerably, rendering it very fine, while its range is extremely limited, the greatest distance to which it will transport coal being at the utmost 150 feet. It can be used at a moderate inclination, say up to 15° from the horizontal.

Summing up the various types described, it may be said that for very long distances the only conveyors available are the gravity bucket and belt, and of these the gravity bucket, though the more expensive and taking the more power to drive it, is the better, since it is subject to less wear and tear, can go in any direction vertically or horizontally, and can be used to bring back material by means of the returning portion.

For distances not exceeding 500 feet, all except the worm are available, and the best is probably the push-plate, as it is the cheapest and requires no attention at the delivery end; it cannot, however, be used to bring back the ashes. For distances less than 150 feet it is to be preferred to the worm.

The power taken to drive the conveyors necessarily varies greatly with the amount of coal to be transported. It is, however, surprisingly small. Thus, with a gravity bucket conveyor of medium size and 200 feet long, only $3\frac{1}{2}$ H.P. is said to be required. A worm conveyor takes about 50 per cent. more power than any other kind. As an example of the power required to drive an elevator, it may be taken that one elevating 50 tons per hour to a height of 40 feet takes only 5 H.P.

It is advisable to put down elevators in duplicate, since a broken chain may necessitate a somewhat lengthy repair, as the buckets will probably run off over the top drum. A conveyor is more easily repaired, and there does not therefore exist the same necessity for duplication, though it is, of course, desirable. The cost of subdividing the risk is considerable; thus, if there be a given quantity of coal to be transported per hour, the cost of two conveyors, to do half the work each, will be approximately 75 per cent. more than the cost of a single conveyor capable of doing the whole work. Even this heavy additional expense may be worth incurring if the storage be not great; if, on the other hand, there is a good reserve, the expenditure is needless.

Conveyors can be made to deal with quantities up to 100 tons per hour. For larger quantities, the links required, and indeed all the portions of the plant, become too cumbrous.

A good deal of care is necessary in the design of conveyors. They have to be carefully fed, and will not work satisfactorily unless supplied with coal in small quantities. None of them will work if buried in coal, and the coal is better in all cases if small; while in some it is essential that it should be so. Wet slack is very troublesome to deal with, as it has a great tendency to clog, and will not flow easily, its angle of repose often being 90°.

Having got the coal into the main bunker, it is usual to allow the coal to fall by gravity into the stoker hoppers. If, however, the store be one of the very large ones mentioned at the beginning of this chapter, there is no way of avoiding a double process, one set of elevating and conveying gear being employed to bring the coal to the main store and another to the subsidiary store from which the stokers are directly fed.

The weighing of the coal, both when it is received into the store and when it is delivered to the boilers, is of great importance; in the first case as a check on the coal contractor, and, in the second, as a test of the performance of the boilers.

When the crane system is used, the coal may be lifted through a steelyard or spring balance, or the crane may run over a weighbridge. All these methods are inconvenient and expensive. They require much attention, and a man whose whole attention must be devoted to the matter; moreover, when a weighing machine is used on a crane, there is much risk of its being damaged. It is possible to utilise some of the automatic machines described

below by discharging the coal through them, but, since the point of discharge is constantly varying, this is not convenient.

With continuously working elevators and conveyors an automatic weighing machine is essential, and, as it happens, is easy to arrange for. Some automatic weighing machines are so only in name, as, instead of measuring the mass, they merely measure the volume, the mass being inferred from this. Since the specific gravity of the coal may vary, there is obviously a liability to error.

One of the most satisfactory automatic weighing machines consists of a containing vessel having both top and bottom closed by curved plates moving somewhat like the jaws of a grab. The top pair are held open, and the bottom pair kept closed, by a weighted lever which is counterbalanced by the coal as it falls in. When the predetermined quantity has entered, the weighted lever is overcome and the top plates close gradually, cutting off the supply, while the bottom ones open and allow the coal to fall into the filler of the conveyor. The number of times the vessel is filled is automatically registered. The machines are usually made to weigh a ton at a time, but the lever can be set to any desired quantity. A similar machine can be used to weigh the coal into the stoker hoppers, but for this work the capacity is usually only one cwt.

CHAPTER XIII.

THE FEEDING OF BOILERS.

OF at least as great importance as any other link in the chain forming the system of generation is the feeding of the boilers with water. Any failure or interruption of this strikes at the root of all, and a breakdown cripples the whole system. Hence, every care must be devoted to making such arrangements as shall ensure a steady ample supply of water to the boilers under all conceivable circumstances.

Before examining the means to be taken to ensure this, it will be well to first consider the feed water itself.

The water may be derived from wells, rivers, canals, or from the ordinary town supply, and its qualities will vary considerably according to the source.

Practically all water contains impurities of some kind, some, however, to a much greater extent than others. The most important impurities, so far as boilers are concerned, are the salts of calcium and magnesium held in solution. The bi-carbonates of the alkaline earths constitute what is known as 'temporary' hardness, because it disappears on boiling, and it is the precipitation of these substances chiefly on the interior of the boiler, forming 'scale,' that has to be guarded against. 'Permanent' hardness, *i.e.*, that which is caused by the chlorides, sulphates, and nitrates of the alkaline earths, is not removed by boiling, but sulphate of lime is also deposited by concentration under pressure.

The evil effects of scale are very great. In the first place, the scale, by diminishing the conducting power of the heating surfaces, greatly reduces the efficiency of the boiler, a deposit only $\frac{1}{16}$ of an inch thick causing a falling off in efficiency of as much as 12 per cent., while the waste increases as the square of the thickness.

There is, however, a further effect of the scale, which is more serious than loss of economy, viz., the deterioration of the boiler itself. The diminished conducting power of the boiler causes the temperature of the plates or tubes in contact with the fire to rise to such an extent, if the scale be sufficiently thick, as to cause the plate or tube to crack or burst.

In other cases, the incrustation may be such as to entirely exclude water from a considerable area of plate, which then becomes much overheated, and the scale may then crack and allow sudden access of water to the plate, causing instantaneous generation of a large quantity of steam, and consequent explosion of the boiler.

The action described is serious with any kind of boiler, but to tubular boilers it is absolutely fatal, and it is imperative that means should be adopted for softening the water.

Various compounds are sold for putting into a boiler, with a view to precipitating the salts in the form of a harmless sludge, but they are not to be recommended, as the sludge, even though not adherent, must diminish the evaporative power of the boiler, while a scum is often formed on the surface of the water, which may cause overheating and priming.

There can be no doubt that the proper course is to treat the water before it enters the boiler, and there are many processes in use for this purpose. If the water contain merely carbonates, or only a small quantity of sulphate of lime, it suffices to heat it in a separate vessel and cause it to throw down its salts therein, instead of in the boiler; but if the sulphate of lime be present in large quantities, it is necessary to resort to chemical precipitation.

It is unnecessary to enter into a description of the various processes in use, but the following may be cited as an example of one which is said to give good results:

A cast iron tank, divided into two equal and similarly arranged portions, is employed, each portion being used alternately for the softening process and for holding the softened water while it is being drawn off.

A measured quantity of the water to be treated is run into one of the tanks, and a solution of the necessary chemicals is forced into the water by means of a kind of injector, so as to cause a circulation of the water through a vertical tube that terminates in a row of perforated horizontal pipes in the lower portion of the tank, the solution being drawn in slowly from a small tank by the current of water.

The chemicals comprise quicklime and sodium carbonate (58 per cent. alkali), and in some cases alumino-ferric in addition. The proportions are varied according to the nature of the hardness, and the solution is boiled by means of live steam.

After thorough admixture of the solution with the water, air is blown in by the same injector through perforations on the under side of a row of horizontal pipes near the bottom. This stirs up the old sediment from previous charges, and greatly assists the deposit of the new precipitate. After blowing for about ten minutes, the steam is turned off, and in about an hour the water is practically clear.

After this the water is carbonated by having mixed with it the gas arising from the combustion of coke. This admixture is effected by forcing the gas, by means of a steam-blower, into an inclined pipe of rectangular section through which the softened water is being drawn off, the water being mixed intimately with the gas by means of baffles.

The amount of carbonic acid required is that necessary to convert the slight excess of alkali used in softening the water into bi-carbonate. The object of this conversion is to avoid a deposit which is liable to be formed in pipes, if water which has been softened is not so treated.

The mud in the settling tanks is removed from time to time.

The cost of softening will depend on the hardness of the water. If only calcium carbonate has to be removed, lime only is required; but if calcium sulphate is present, alkali must be added, while magnesium salts require caustic alkali. The cost of softening water containing magnesium salts is hence the heaviest. The amount of steam necessary is only that required to raise the temperature by about 2° F., and the greater part of this is, of course, returned to the boilers. The cost of the chemicals for softening water, in certain actual cases, varied from 0·2 penny per 1000 gallons for water containing 24·75 grains of salts per gallon, having a calculated hardness of 15·65°, to 4·2 pence per 1000 gallons for water containing 114·37 grains per gallon with a calculated hardness of 61·95°, quicklime being £1 per ton, and 58 per cent. alkali £4 per ton.

As regards the space occupied, a plant capable of softening 60,000 gallons per hour would comprise four tanks 27 feet 6 inches square and 10 feet deep.

It will be observed that the process is an intermittent one, but continuous methods exist, though it is doubtful whether the correct proportions of the added chemicals can be so accurately gauged as in that just described.

The following is an excellent example of a continuous process: The water to be softened is pumped into a T-shaped trough, at the end of which it flows over a sill, nine-tenths of it into a water wheel, and thence to the top of a tall vessel, the remaining tenth into a small vessel, whence it goes into an automatic mixing apparatus for the chemicals. The sill being accurately planed, and the length of the sill being adjustable, the proportion of water going into the mixer can be varied as required.

The automatic mixer is used alone if lime be the only chemical required, and the quantity of lime added is very simply determined by the number of gallons of water passing through a hopper containing the lime, since a gallon will only dissolve a certain quantity. The water that passes through the mixer is cleared by being passed down a tube and up a half annular space round it, and on emerging from this is mixed with the remaining nine-tenths of the water as it falls from the water wheel. The precipitate

in the water is caused to fall by allowing the water to pass slowly over a number of settling plates, placed one above the other about a foot apart. These plates are inclined in such a manner that the deposit slides gradually to the bottom, whence it is removed by means of a sludge cock.

When other chemicals than lime are necessary, they are added to the mixer by means of a little bucket conveyor, driven by the water wheel, the revolutions of which are, of course, proportional to the rate of entry of the water, a sufficient quantity to last for a day being dissolved in the vessel whence the conveyor takes its supply.

Before discharge, the water passes through a filter to remove any light particles there may be.

The water is not carbonated, and hence it is not softened below two or three degrees.

In ordinary cases, the cost for chemicals is stated to be about one penny per 1000 gallons softened. The apparatus requires less floor space, but more head room than the one already described.

In a modified form, this apparatus can be made to work under pressure.

Besides mineral salts, water may contain vegetable matter of a glutinous character that may be deposited in a thin film, and, if salts be present also, the coating may become so hard as to be incapable of removal. Or, again, there may be solid matter in suspension; this can obviously be got rid of by allowing the water to stand.

So far we have considered impurities that cause the deposition of scale. Some waters, however, are excessively soft, but contain, in place of salts, various gases, in solution. These are usually oxygen, nitrogen, and carbonic acid, with, occasionally, sulphuretted hydrogen. The action of these gases is directly opposed to that of the salts, *i.e.*, they cause corrosion, usually taking the form of pitting. In order to neutralise the effect, it suffices to add to the feed water a solution of 'crystal carbonate,' containing 58 per cent. of pure alkali. This may either be added to the water before it is pumped into the boilers, in which case there is danger that the packing rings of the pumps may be damaged; or it may be injected by a small special pump directly into the boiler or economiser; or, finally, a kind of flush cup may be fitted to the boiler, and the fluid put in at intervals. The continuous injection of small quantities is certainly to be preferred to the last method, so far as the boiler is concerned.

Seeing how much harm may be done by bad water, it is well worth while to secure the best available, even though its price may be high; in the long run, it will probably lead to the least expenditure. When using river, and especially canal, water, it should be ascertained whether any chemical works are situated on the banks, since these often discharge highly deleterious liquids, which would rapidly play havoc with the boilers. Such contamination might readily be undetected by the analysis of a sample, because the

discharge is intermittent, and the water might be free from the substances when the sample was taken.

Very frequently boilers are fed with the condensed steam from the condensers, as much fresh water being added as is necessary to make up for the loss in volume by leakage and evaporation. Even though the water be perfectly pure in the first instance, it will become contaminated with the oil used for the lubrication of the cylinders, and this will be even more destructive than any of the other actions already referred to. The oil forms a film on the surface of the plates or tubes, and leads to their rapid burning out.

It is thus essential that the oil should be removed from the water before such water is returned to the boilers. There are many devices for doing this, though none appear to be wholly satisfactory. Most of the arrangements are filters of some form or other, the intercepting material being either coke, waste, saw-dust, or some similar substance. The filters are a source of considerable trouble, and must be frequently cleaned; for this reason they have to be in duplicate.

Another way in which it has been attempted to extract the oil is by means of an ordinary cream separator. This method gave good promise of success, but it was found that the apparatus in the market was not adapted to continuous running; there seems, however, to be no valid reason why this process should not be made a success.

Quite another class of separator is founded on the principle that it is easier to extract oil from steam than from water. In a separator so designed, the steam is first allowed to enter a chamber, where it expands, and therefore cools, and also has its velocity reduced. The oil is thus liquefied, and some of it deposited on a curved plate which directs the steam on to the surface of some water at the bottom of the chamber; this causes further deposition of oil on the water. The steam finally passes between a number of angle iron bafflers, placed in a chamber of large area, so as not to hinder its flow, and these extract the rest of the grease, the steam passing on to the condenser. The chief drawback to this separator is the large amount of space occupied.

The feed water may be forced into the boilers either by injectors or feed pumps. Injectors, which are too well known to require description, are usually employed as a standby to pumps; they take a large quantity of steam, but, as this passes directly into the feed water, the greater part of the heat is saved.

Feed pumps may be either steam-driven or motor-driven; much difference of opinion exists as to which of the two is to be preferred.

On the one hand, most steam-driven pumps are exceedingly inefficient, the steam consumption running up to an incredibly high figure, 45 lbs. of steam per horsepower hour being an exceptionally good performance for an ordinary direct-acting pump. At the same time, they are simple and

compact, their speed can be varied over a wide range by infinitesimally small steps, their first cost is reasonable, and the cost for repairs is small.

On the other hand, electrically-driven pumps are undoubtedly more efficient, though less so than is generally supposed, owing to the double conversion of energy, the loss in leads, and the low efficiency of gearing; and distinctly more cleanly. Among their disadvantages must be reckoned high first cost, heavy wear and tear of gearing, complication, excessive floor space, and, above all, difficulty in efficiently varying the speed over a wide range.

Steam pumps can be rendered much more economical by being compounded, or even made to work triple expansion, and by being fitted with condensers. If the efficiency be thus increased, however, it is at the expense of additional complication, involving more risk of breakdown and increased repairs.

With the plain direct-acting pump much of the waste may be saved by attaching a feed-water heater to it. This utilises a large proportion of the heat in the exhaust steam, and may even give a few inches of vacuum, while the apparatus is neither costly nor troublesome to maintain. Where the feed is not taken from the condensers, this method supplies the best means of warming the water before it enters the economisers.

In coming to a decision between steam and electrically-driven feed pumps, it will thus be seen that a balance has to be struck between a cheap, reliable, convenient, compact, but inefficient pump, and one that is more efficient, but costly, none too reliable, bulky, and limited in range of speed. In the Author's opinion, the direct-acting steam pump, fitted with feed-water heater, is to be preferred when cold feed is used, the advantage of being able to warm the water before it enters the economiser being sufficient to turn the scale in its favour. When, however, water is taken from the hot well, this advantage disappears, and the two types appear to be much on a par; even here, however, the Author would be inclined to decide in favour of simplicity.

The steam consumption is more usefully expressed in pounds of water pumped per pound of steam than in pounds of steam per horsepower hour. In the case of a direct-acting pump, tested by the Author, capable of delivering 7500 gallons per hour against a pressure of 125 lbs. per square inch, the slip (when the delivery was closed, and with full steam pressure on the piston) was *nil*, and 90 lbs. of water were pumped per lb. of steam. The repairs on a similar, but slightly smaller pump, in a whole year, only amounted to the cost of a new packing ring. What would have been the cost of upkeep of an electrically-driven feed pump of similar size?

The Author would, however, prefer an electrically-driven feed pump to a complicated steam pump, as the latter lacks simplicity, the very feature for which a steam pump is to be recommended.

Before leaving the subject, there is one other consideration that should not be lost sight of. In the event of some exceptional breakdown, necessitating the shutting down of the station, a disaster might readily ensue if the boilers were steaming rapidly at the time, and there were no means of supplying them with water, as would be the case if the pumps were electrically driven from the main supply, but not with steam-driven pumps.

It is desirable to so arrange the pumps that they are normally 'drowned,' *i.e.*, the supply reservoir should be at a higher level than the pumps, so that no work has to be done on the suction side. This is especially necessary if hot water is to be pumped.

The feed pipes must be so arranged as to reduce the risk of failure to a minimum, for which purpose they are nearly always duplicated. A common arrangement is to have a few large pumps delivering into either of two ranges, from each of which a connection is taken to each boiler.

This arrangement is open to several objections. It requires a great length of piping and many valves, and is therefore costly. It is also complicated, especially if economisers be used, as it is then necessary to arrange either for feeding direct or through the economisers. Moreover, with many boilers there is considerable difficulty in properly feeding those furthest from the pumps, and, if there be several economisers in parallel, it is almost impossible to make them properly share the work (see above, p. 81).

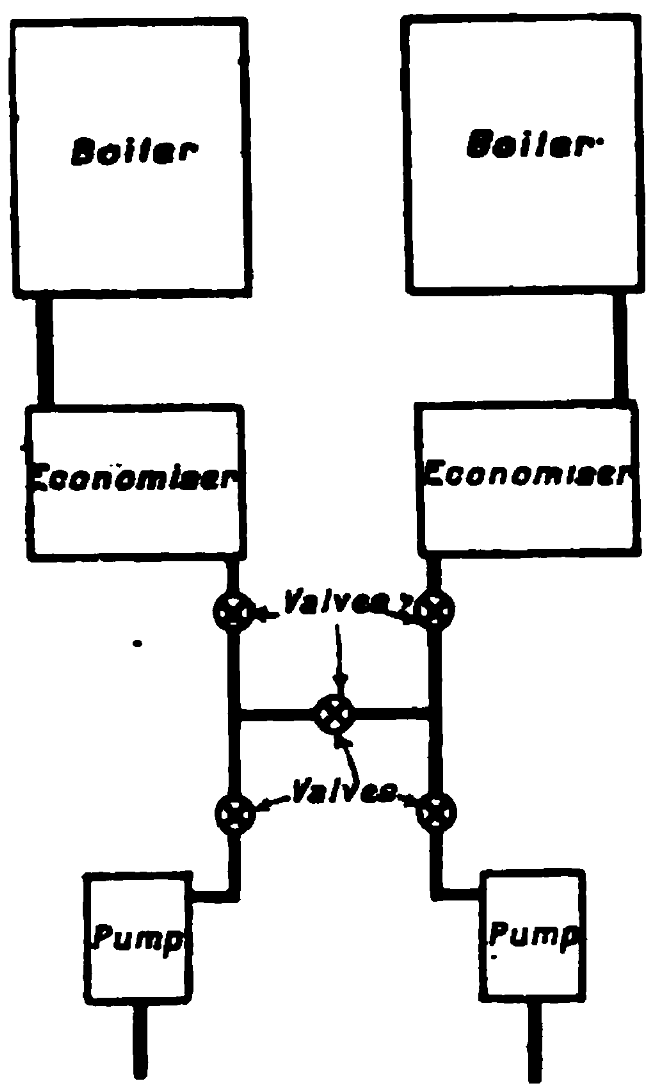


FIG. 18.—Arrangement of feed pumps.

An arrangement adopted by the Author in the case of a battery of Babcock and Wilcox boilers, capable of evaporating 200,000 lbs. of water per hour, is shown diagrammatically in fig. 18. Each boiler is provided with a pump capable of supplying water at double the rate required by each boiler; in the case in question, each pump will deliver about 4000 gallons per hour against a boiler pressure of 160 lbs. per square inch. Each boiler has its own economiser, and its pump forces the water directly into this, or, by means of a byepass, straight to the boiler. The deliveries of the pumps are connected by means of a pipe on which is placed a valve. Under normal conditions, each pump supplies its own boiler, but, if either be disabled, the other can supply both boilers. The advantages of this scheme are: (1) great saving in cost of piping, there being no ranges, and the amount of piping and valves being reduced to a minimum; (2) extreme

simplicity; (3) a greater diminution of risk of disablement of the whole battery than with the duplicate arrangement first described. The disadvantages are: (1) substantial increase in first cost of pumps; (2) increased amount of repairs, owing to augmentation of number of pumps. As regards efficiency, there is probably little difference, for although, when working at the maximum rate, the few large pumps would probably be the more efficient, yet at times of light load the advantage would probably be on the side of the small pumps.

Care should be taken to have as few bends as possible in the feed pipes, and, when these are unavoidable, they should be as slow, *i.e.*, as well rounded, as possible. The pipes should be of ample area for the water they have to carry. Due allowance must also be made for expansion on long lengths.

The pipes may be of cast iron, or, preferably, of cast steel, especially for large sizes and high pressures. The joints are flanged and bolted together, rubber being the most suitable jointing material.

CHAPTER XIV.

THE TRANSMISSION OF STEAM.

We now pass on to the steam pipes for conveying the steam generated by the boilers to the engines. It is a first essential that steam shall be available under all circumstances for every engine, and, hence, that a severe leakage in any part of the system shall not disable any engine, or, at the worst, shall only necessitate the stopping of one.

This freedom from interruption in the steam supply can be attained, primarily, by skilful design and the employment of first-class material and workmanship, and, secondarily, by providing a duplicate or alternative supply to the engines.

Other points of importance, inferior only to continuity of supply, are the reduction of the area of radiating surfaces to the minimum amount, the making of proper provision for variation in length, due to change in temperature, and the proper draining away of water.

It will be convenient to first consider the general arrangement of the pipe ranges. In stations of moderate size, it has been usual to so arrange matters that every boiler shall be capable of supplying any engine by either of two paths. This arrangement is known as the 'ring' system, the simplest form of which is shown diagrammatically in fig. 19. In this it will be seen that, under normal conditions, the steam generated by the boilers passes by two paths to the engines; while if a leak occur at any one point, the section containing it can be cut out by closing two valves, all the steam passing in one direction through the range, if the damage be on a section between boilers and engines, or partly through one portion and partly through the other, if the damage be between adjoining boilers or adjoining engines.

It is to be noticed that with this arrangement: (*a*) The range must be of uniform size throughout, and must be large enough to carry the steam when generated at the maximum rate, since any portion may be called upon to carry the whole supply. (*b*) A damaged section may disable one boiler or one engine, and the chances are in favour of its doing so. (*c*) A large number of valves are required, and they are all of the size of the main range.

(*d*) The system allows of provision being made for changes of length with variation of temperature.

The simple ring system may be further developed by cross-connecting it

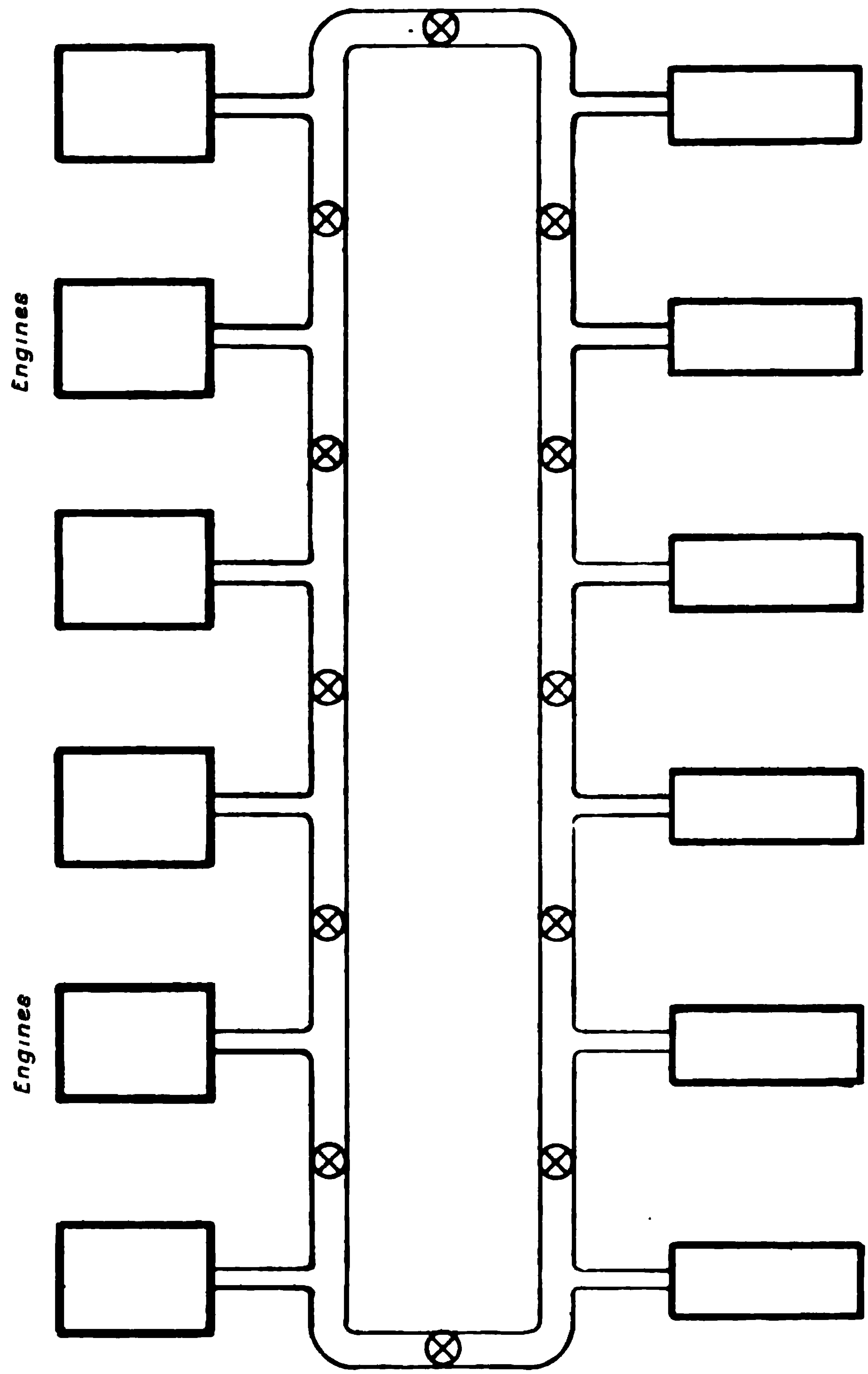


Fig. 19.—Ring system of arranging steam pipes.

at various points, as shown in fig. 20. Comparing the two systems for the same boilers and engines, it will be seen that (*a*) The size of the pipes forming the ring may be diminished, thus reducing its cost and radiating surface.

Against this must be set the cost of the cross-connecting pipes and their radiating surface, the magnitude of which two items will depend upon how near the boiler and engine sides of the ring are together. (*b*) The risk of a

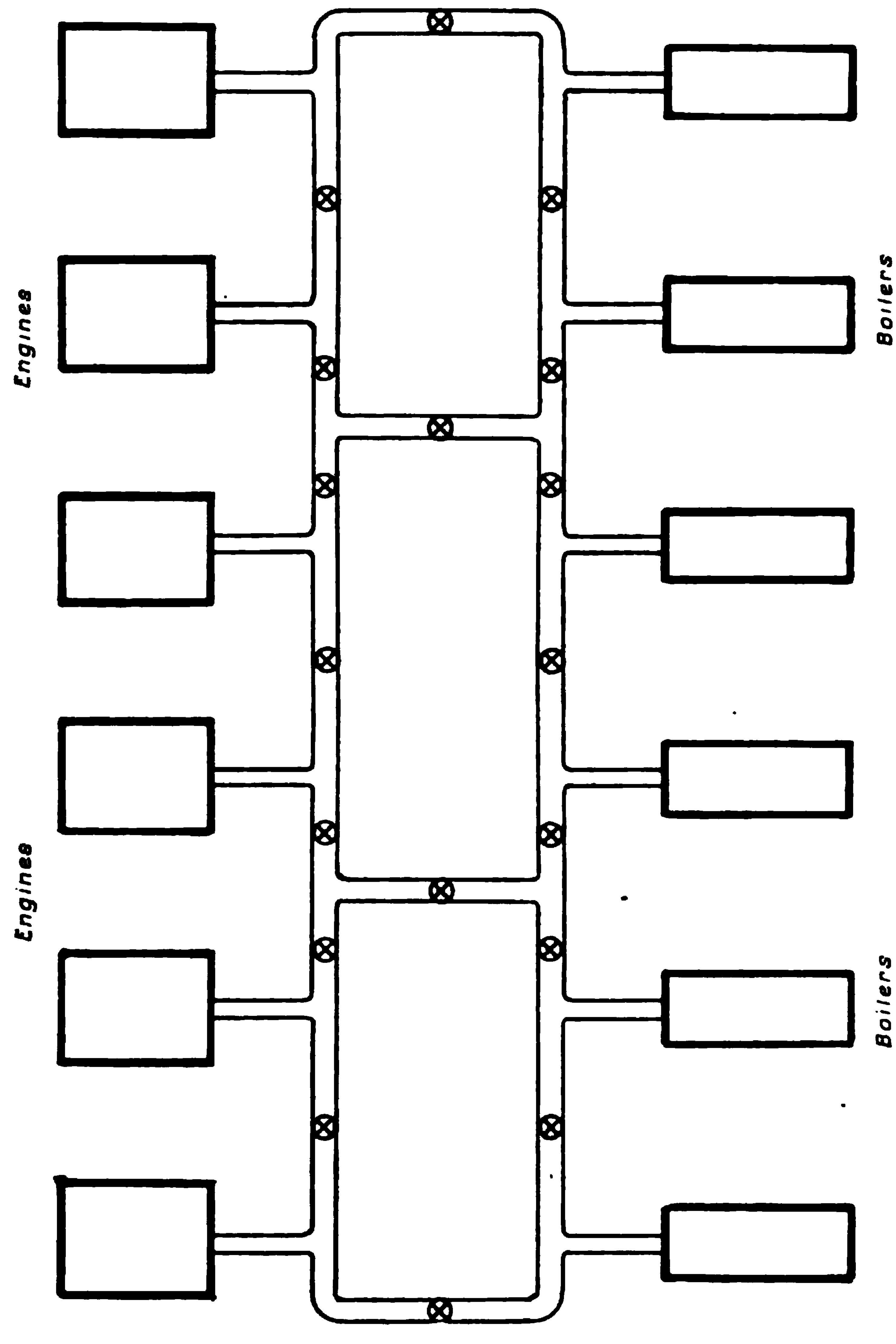


FIG. 20.—Ring system of arranging steam pipes, with cross connections.

boiler or engine being disabled is diminished. (*c*) The number of valves is increased, but their size is diminished. (*d*) Changes of length, due to temperature, are less easy to deal with.

A third system is shown in fig. 21. The Author is not aware that it has

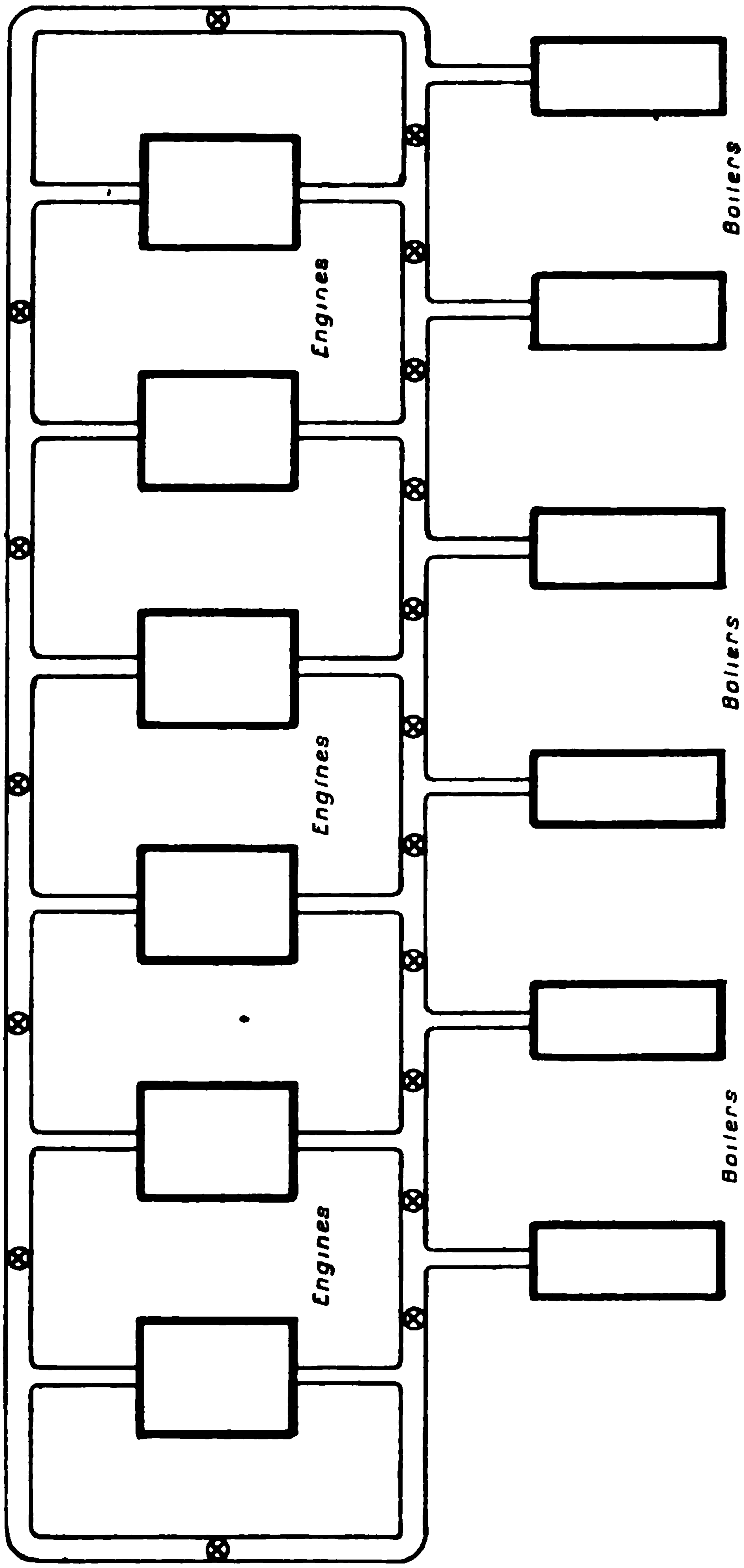


FIG. 21.—Ring system of arranging steam pipes, with engine connections duplicated.

actually been used, but it is a possible arrangement that is worth noting. It

is a simple ring combined with a semi-duplicate system, the duplication being confined to the engine connections. The number of valves is very large, but the pipes need not be as large as in the simple ring. It is practically impossible for an engine to be disabled.

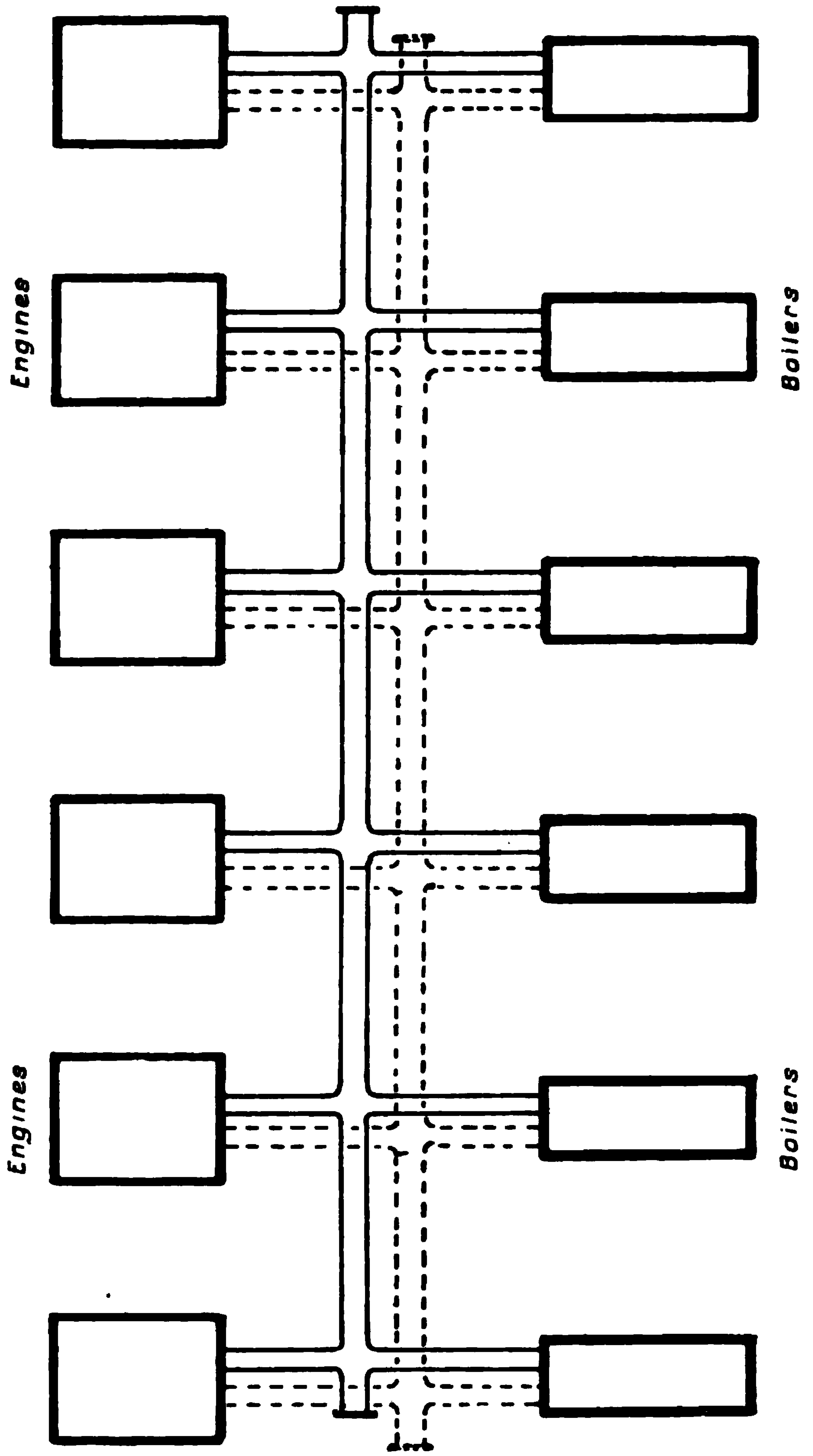


FIG. 22.—Duplicate system of arranging steam pipes.

A much less common method of guarding against breakdown than the ring system is to provide two absolutely distinct ranges, and to connect every boiler and every engine to both. Fig. 22 shows the connections. There is thus secured practical immunity from disablement for every boiler and every

engine. With engines and boilers in the same relative positions as before, the amount and size of piping is not greater than with the ring system, and the whole of the large valves are eliminated, though the number of valves on the boiler and steam connections is doubled. Of course, if one range is disabled at any one point, the whole range must be shut off, but the risk of interruption is not greater than with a ring main.

With all the systems described, there is considerable difficulty in keeping the valves steam-tight, the chief cause being the fact that the pressure is sometimes on one side and sometimes on the other, and, in the case of ring systems, the valves are so rarely used that they are apt to become fast. The defective valves render it very difficult to get steam off any section of a ring, or off either range in a duplicate system, and the resulting inconvenience is considerable.

The arrangements described are only suitable for stations of moderate size, *i.e.*, for those in which the individual engines do not exceed, say, 400 or 500 H.P. In large stations the number of boilers and the space they occupy are so much larger than the number of engines and the space they require that the same arrangements cannot be applied. It becomes necessary to treat several boilers as the unit, and to arrange for such batteries to be interchangeable on the engines.

With this modification, the same methods can be applied up to a certain size, but a point is reached when the size of pipe necessary as a main range, in order to enable any battery to feed any engine, becomes so enormous as to be quite impracticable, so that then complete interchangeability must necessarily be abandoned.

A feeling against all systems of ring and duplicate steam mains has arisen, and is becoming so strong that there is danger that the reaction will lead to a lack of due caution. It would seem that in all stations where the relative size of boiler and engine may be such as to admit of one boiler supplying several engines, it is best to retain the old practice of ring or duplicate; but in large stations, where one boiler, or a battery of boilers, goes to a single engine, the interchangeability may be materially modified.

In fig. 23 is shown what the Author considers to be the best disposition for a large station. Here each engine is normally supplied by its own three boilers, but, if necessary, it can be supplied from the adjoining three, but not from any others, unless the intervening boilers and engines are out of use. The main range between the extreme engine branches is of sufficient size to carry the steam generated by three boilers, and is divided up by valves so that each section of three can be isolated. All pipes are kept of reasonable size, and the radiating surface reduced to a minimum, the number of valves is not great, and only one engine (with its boilers) is liable to disablement. These advantages are gained at the expense of complete interchange-

ability (which is really quite unnecessary), and the simultaneous disablement of three boilers, if their section of the main range is damaged.

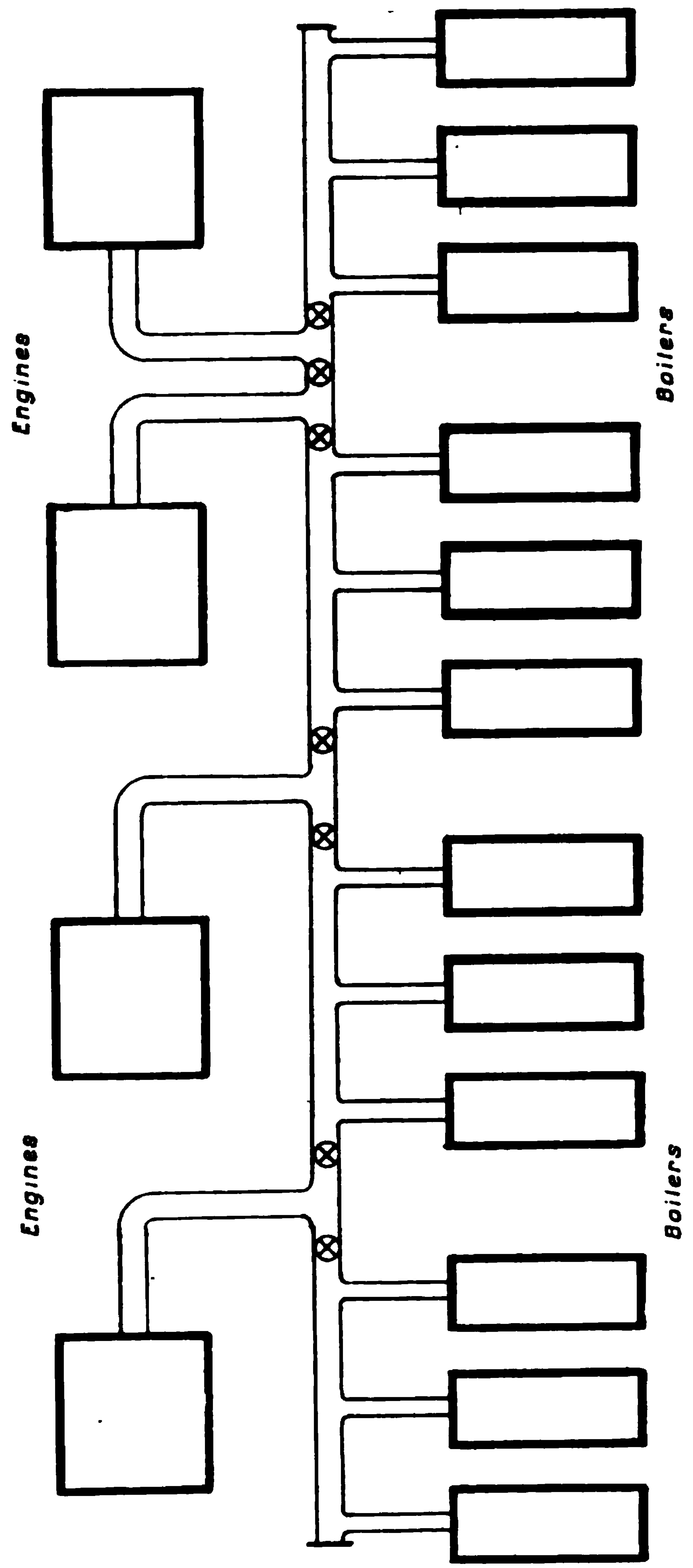


Fig. 23.—Method suitable for a large station.

The above arrangement is available only if the type of boiler adopted is sufficiently compact to allow of the boiler house being no longer than the engine room. If this be not the case, the boilers must be arranged in a number of batteries, each battery being as short as possible, and being treated as a unit. An arrangement schemed out by the Author for a station of 50,000 H.P., employing Lancashire boilers, is shown diagrammatically in fig. 24. Here seven boilers are taken as a unit, and are connected directly to the engine range, cross connections between the two sets of seven being established on account of the great length of the connections and consequent risk of failure. This is sufficient to demonstrate

FIG. 24.—Arrangement of steam pipes for large station with boilers occupying large floor-space.

the great evils of boilers of small capacity per square foot of floor-space for large stations, the length of pipe being enormous.

Steel expands about $\frac{1}{150,000}$ part of its length for each degree Fahrenheit, and the temperature of saturated steam at a pressure of 160 lbs. per square inch is 363° F. Hence the difference in length of a pipe 100 feet long, when it is at work, and when it is off, is about 2¼ inches. The force necessary to produce, and, therefore, that required to restrain, this expansion is exceedingly large, and there is no choice but to allow it to take place; the problem to be solved, then, is how to arrange for this and yet keep the range tight and the connections to it free from strain.

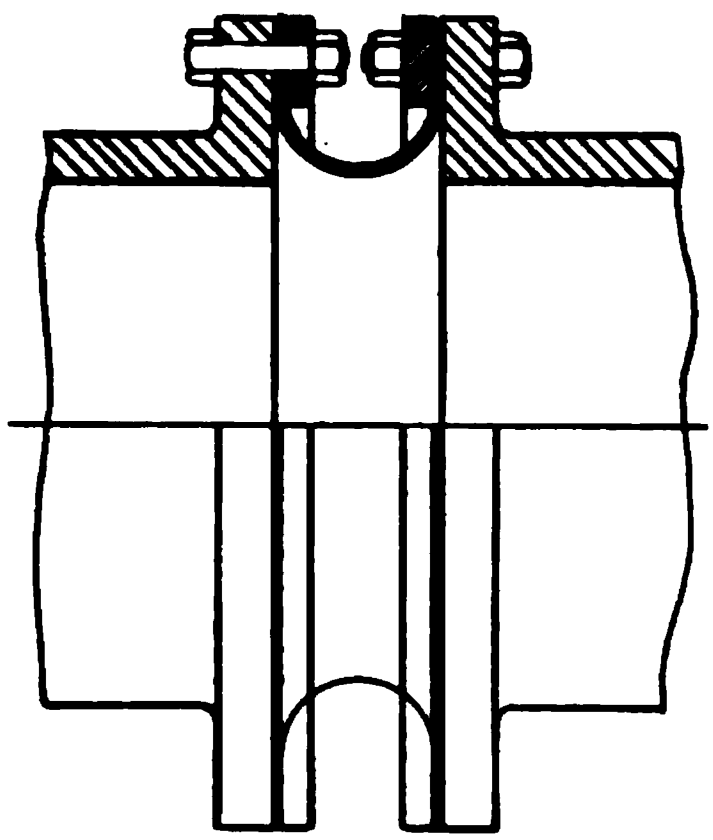


FIG. 25.—Bellows joint.

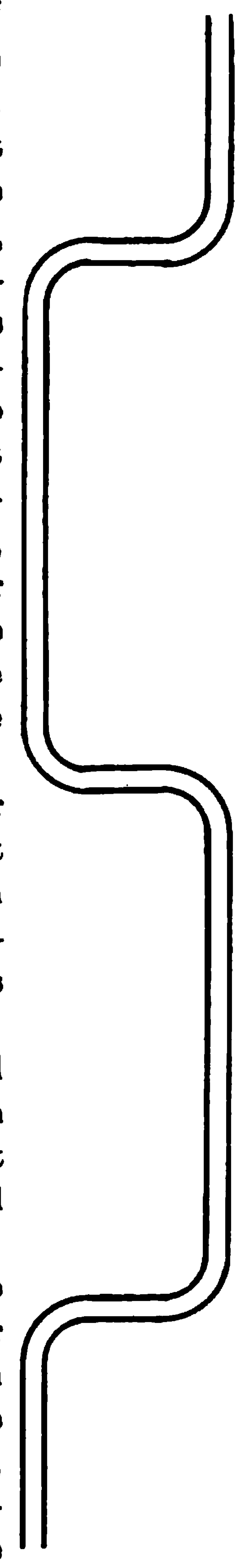


FIG. 26.—Disposition of steam range to admit of expansion.

The first point that will be obvious is that the shorter the pipes can be made, the less will be the actual amount of expansion, and the less the difficulty in dealing with it. In very short lengths, the compressibility of the jointing material at joints will suffice, if the branch connections to engines and boilers be long and therefore flexible.

Such short lengths are, however, rarely met with, and it becomes necessary to devise some form of 'expansion joint,' *i.e.*, a connection that will carry the same amount of steam as the steam pipe, yet suffer compression and extension without injury.

There are various kinds of such joints in use. The bellows or concertina joint consists of a sheet of copper bent, as shown in fig. 25, the edges being gripped between the flanges of the pipe and the ring. Another form is the sliding joint, in which one pipe is attached to a cylinder, bushed with gun-metal, which slides, or rather is supposed to slide, in a similar cylinder attached to the other pipe. This is perhaps the most unsatisfactory joint of any, as the sliding portion nearly always makes up and becomes as rigid as the pipe itself. In the case of small pipes, the most satisfactory way of dealing with the expansion is to avoid keeping the range in one straight line, as

indicated in fig. 26, so as to allow the elasticity of the material to take up the expansion. If this cannot be done, a copper U-shaped pipe is often used, but, although quite effectual, there is danger that the copper may become brittle in time, and, if used, it should be periodically annealed. With superheated steam, copper should be avoided altogether.

For pipes of large diameter, copper is unsuitable, and the Author has found nothing so good as a welded steel or wrought iron tube, or several in

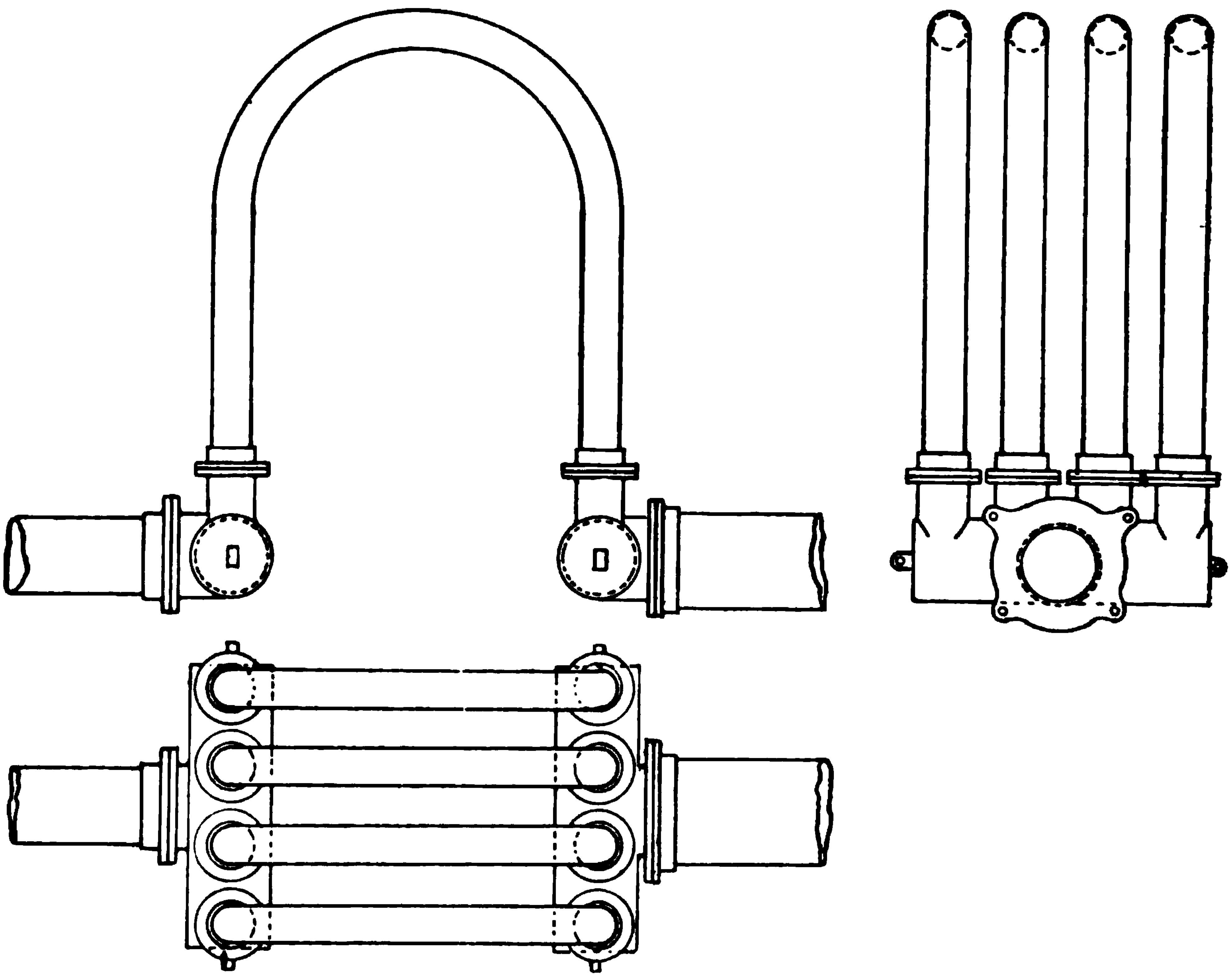


FIG. 27.—Parallel U-joints.

parallel, the legs of the U being made as long as possible. An expansion joint of this type, devised by the Author for connecting two main steam pipes, one 18 inches diameter, the other 14 inches diameter, is shown in fig. 27. There are four steel pipes, each 7 inches diameter, and 8 feet from the base to the top of the bend of the U; they are connected at their ends by steel castings of T form, bolted to the main ranges. This joint has been in use for between four and five years, and has required no attention of any kind, while it has prevented all trouble from expansion on the pipes it was

intended to save. It is, of course, necessary to properly drain both sides of the U.

All expansion joints require control by bolts in order to limit their movement; without this, the sliding joint, for instance, might have its two halves blown apart. Further than this, it is necessary to securely anchor the ranges to which the joints are applied, so as to ensure the movement taking place at the joint and not elsewhere.

The very worst form of construction, so far as expansion is concerned, is

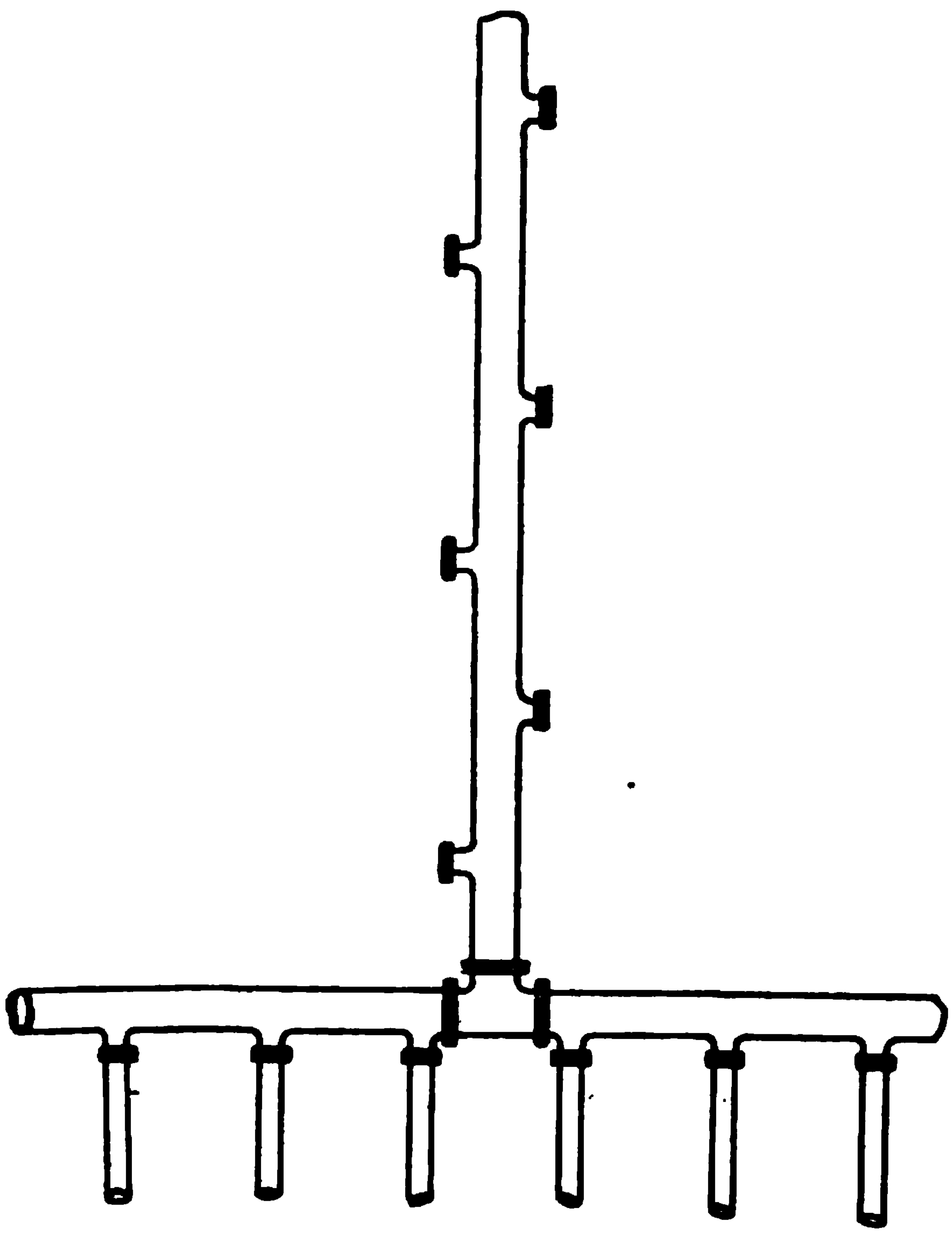


FIG. 28.—Bad arrangement of steam pipes.

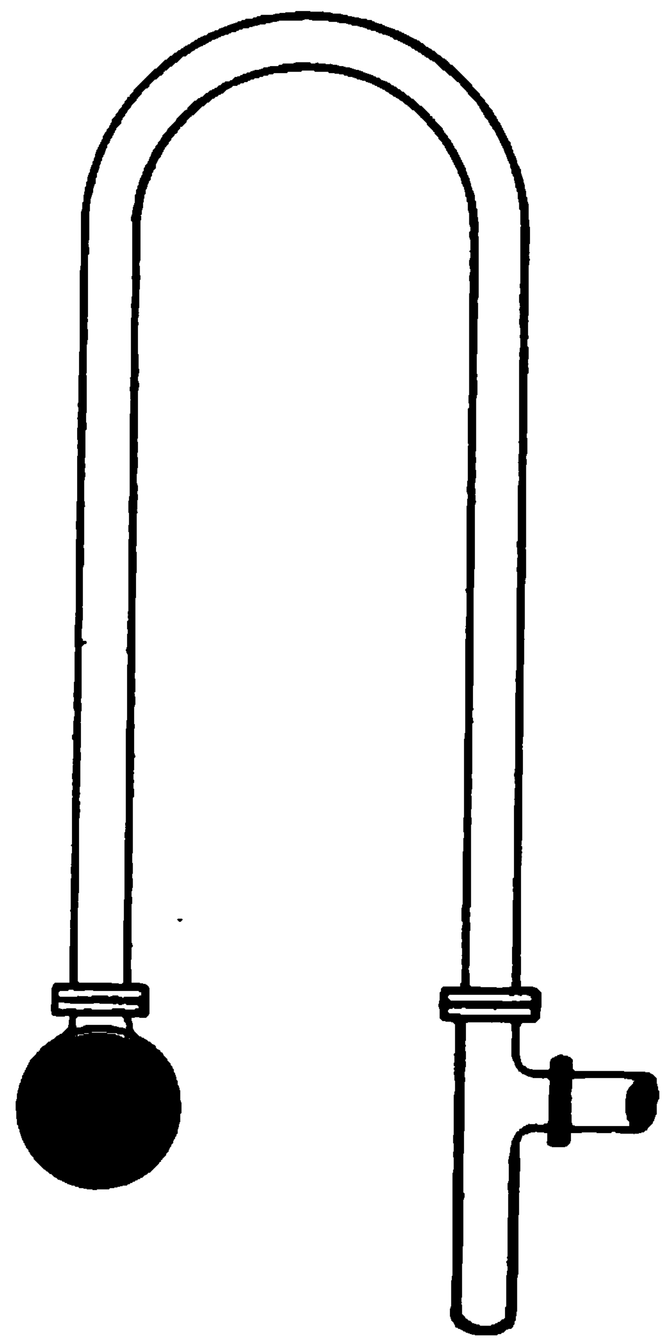


FIG. 29.—U-connection to boiler.

to have two large pipes T'd together, as shown in fig. 28. In this case, the whole of the thrust of the pipe supplying the engines comes at the middle point of the boiler range, and has to be borne by the boiler stand pipes. The result is to cause the joints on the latter to break. In a case where this arrangement was unavoidable, the Author completely cured the trouble by connecting each boiler through a U-pipe of steel, as shown in fig. 29, a cast steel drop pipe being added to avoid the chance of water accumulating when the boiler junction valve was shut.

Besides the arrangements just described, it is important to so support

the pipes that they shall be free to move. The chief means used are to support the pipes at intervals on cast iron columns, each carrying at its top a small curved bracket, which fits the curvature of the pipe, and is adjustable for height by means of a bolt and nut; another method consists in carrying them on brackets furnished with rollers; while a third way is to sling them by means of wrought iron rods from the under side of brackets.

All these methods are satisfactory, and may safely be adopted. It is well, however, to remember that a certain amount of constraint is necessary. The Author has seen an 18 inch range, in which the constraint had been omitted, vibrating in so violent a manner that distinct waves could be observed traversing the whole length of the pipe, and giving it a snake-like movement.

It is advisable to keep as large a proportion of the steam pipes as possible in the boiler house, as, by so doing, the engine room will be kept cooler, and the risk of damage to the generating plant by steam or water reduced. It is desirable to keep the pipes below the floor, if possible; chiefly because they are in this manner preserved from changes in temperature, due to the weather, and partly because there is less risk of damage from a leaky pipe or joint. From the point of view of appearance there is also great gain.

The radiation losses from steam pipes are proportional to their temperature and the area of surface exposed, also to the emissivity of the surface. They may be greatly reduced by covering the pipes with a suitable non-conducting composition.

Many compositions are in use; it is unnecessary to enter into particulars of them, but it may be pointed out that they should be incombustible, should present a hard smooth surface that can be readily freed from dust, they should not be brittle nor easily damaged by accidental knocks, they should not be readily affected by water or steam, and they should present as large a resistance as possible to the passage of heat through a given thickness. The importance of this last item should not be overlooked, for, if there be two materials, one of which has to be applied of twice the thickness in order to offer the same resistance to the passage of heat, the one that is in the thinner layer, even though its cost per pound be more than twice as much, is to be preferred, for the greater thickness involves a larger finished diameter and therefore an augmented radiating surface. It is desirable to varnish the covering, as this diminishes the emissivity, and enables the surface to be kept clean.

It is not unusual to neglect to cover the flanges of pipes, no doubt because it is desired to leave them free for rejointing. The loss from these joints may, however, be considerable, especially as the flanges act as gills, and hence radiate more heat than a corresponding length of plain pipe. The covering should be so put on that it may be readily removed when necessary. This

provision is sometimes made for the whole of the covering, but it is difficult to see any advantage in this.

The drainage of steam pipes is a matter of great importance, because (1) any water carried into the engine cylinders may do serious damage; (2) an accumulation of water may be suddenly carried along by an increased flow of steam, and give rise to 'water hammer'; and (3) the water may cause unequal expansion and contraction, so as to give rise to leaky joints.

It must be remembered that the problem of draining a pipe through which steam is passing with a high velocity is a very different matter to draining the same pipe when merely filled with steam. Water may readily be blown by the steam up an inclined pipe down which it would ordinarily run.

There are thus two distinct matters to be dealt with, viz.: (1) the removal of the accumulation of water in places where it may collect by gravity; and (2) the removal of the water entrained in the steam.

The first accumulation may be looked for at the bottom of bends and of upright sections of pipe, such as the legs of the U-pipe expansion joints, for example, and is usually drained away by 'steam traps,' *i.e.*, a species of apparatus which is arranged to automatically allow water to pass, but to close as soon as steam arrives.

The number of traps in the market is very great, but they all depend on one of two principles for the opening and closing of the valve that allows the water to pass and shuts off the steam. These are: (1) difference in the amount of expansion of dissimilar metals with change of temperature; (2) varying position of a float borne by the water of condensation. The second class falls into two subdivisions, according as the float is under pressure or not.

One of the most deservedly popular of the traps working on the first principle is the Geipel, which is exceedingly simple and cheap. It consists of two long tubes, one of iron, the other of brass, coupled together to form an isosceles triangle of very short base. The ends next the base are rigidly connected to the casing of the trap, while the other ends are attached rigidly to one another by means of a coupling containing a valve, but are free to move relatively to the casing. The brass pipe is connected to the point to be drained by a pipe at least three feet long, in order to secure that the water shall be substantially cooler than the steam. The iron pipe is the outlet. The valve in the coupling is held in position by a lever pressing on a stud connected to it, so adjusted that it is closed when the brass tube is full of steam. When the temperature of the steam falls, owing to water cooler than the steam entering it, the difference in expansion of the brass and iron tubes causes the apex of the triangle to move downwards, and the valve, being no longer pressed down by the lever, is opened

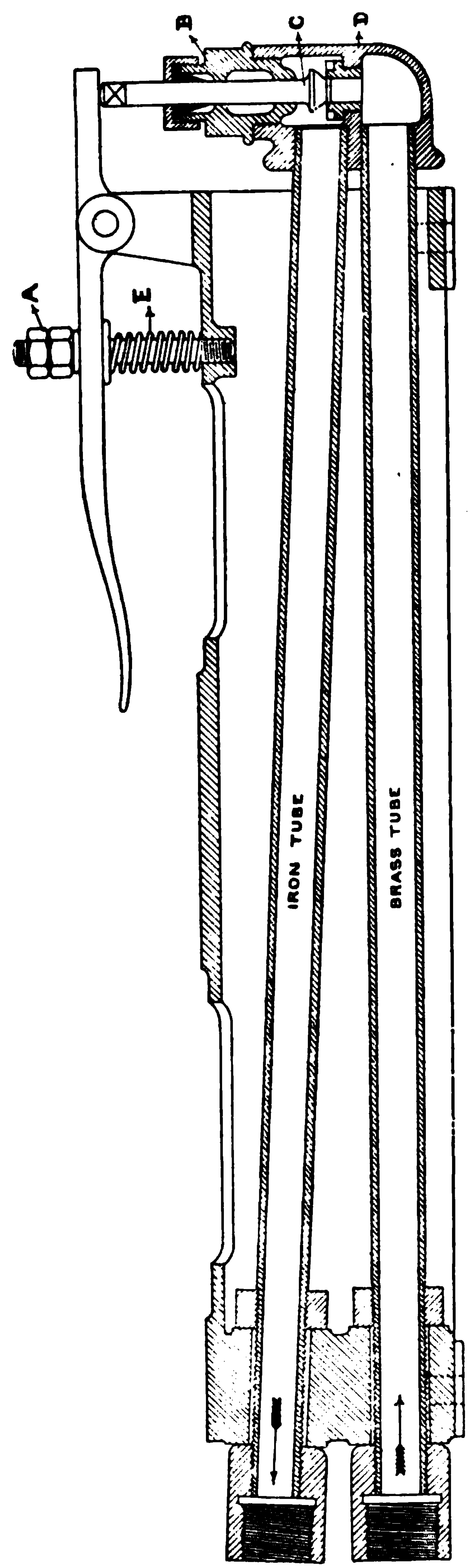


Fig. 30.—Geipel steam trap.

by the steam pressure and the water blown out; as soon as the steam again enters the tube, the latter regains its temperature, and the valve is forced back again on its seat by the stud bearing against the lever. The trap is shown in fig. 30.

Another example of this class of trap is the Sirius. In this there is a sealed steel tube bent into a semicircle, and filled with a fluid; one end is fixed and the other is free, and carries a valve which controls the entrance of steam into the chamber in which the tube is fixed. The adjustment is so made that the valve closes at the temperature of the steam. When water begins to collect, the bent tube contracts and opens the valve, allowing the water to be discharged; as soon as the steam enters the casing, the tube expands and again closes the valve. The trap is shown in fig. 31.

As an example of the first subdivision of the second class, namely, those traps which are actuated by a float working under pressure, may be cited the Turnbull trap. In this a strong cylindrical vessel contains a cylindrical float, free to move in a vertical direction. The float is open at the top, and so does not tend to collapse under the steam pressure. It is suspended by

means of a strong spiral spring, and its base carries the valve. The spring is of sufficient strength to take up the weight of the float. The steam inlet is at the top of the containing vessel, the water outlet at the bottom.

FIG. 31.—Sirius steam trap.

The water collects in the vessel until it reaches a height sufficient to raise the float; when this happens the water is, of course, discharged, and the float then falls. (*See* fig. 32.)

The second subdivision of this class is to be preferred, namely, those in which the float is not under pressure.

An exceedingly reliable example of this system is the Lancaster trap. In a containing vessel is placed a copper ball, carried by an elbow pipe, having at its other end a quick-threaded screw, which enables it to open or close a valve, against which its end is pressed, according to the position of the ball. The ball is perforated with a small hole at the bottom and with a large hole at

FIG. 32.—Turnbull steam trap.

the top; into the latter is screwed a pipe which passes within the ball and reaches nearly to the bottom. The end of the tube outside the ball is open. The containing vessel is kept about half-full of

water, the outlet from the container being placed at a suitable level to secure this. If condensed water be present, the ball is at the bottom of the vessel, and the steam valve therefore open. The water to be drained away flows through the valve and the elbow pipe into the ball, and thence through the large tube out of the top of the ball. Immediately the steam following the water reaches the valve, it blows the water out of the ball, which then becomes buoyant and rises, closing the valve and shutting off the steam. The ball then gradually fills again with water, which enters through the small hole at the bottom of the ball, and, in course of time, it drops, to be immediately blown out and rise if there be no water behind the valve, or to remain down, if there be water condensed, until it is all discharged. The Lancaster trap is shown in fig. 33.

Fig. 33.—Lancaster steam trap.

In fixing traps, the pipe leading to them should not be too large, otherwise it will itself effect condensation, and so add to the amount of water to be removed by the trap. On the other hand, the pipe leading from the outlet should be of ample dimensions.

The water is discharged from the traps at a high temperature, and should be collected and returned to the boilers. Traps are sometimes arranged to themselves raise the water, but this is undesirable, as the head of water may interfere with the proper working of the trap. It is preferable to collect the water in a small tank and raise it by means of a pump or injector.

Another system of draining which has not yet been tried to any great extent in this country, though it is in use in America, is known as the 'gravity return' system. Instead of draining off the water by means of a number of separate traps, all the points that require draining are connected through non-return valves together, and to a common receiver wherein the water collects, and whence it is forced by a kind of injector up a vertical pipe to a considerable height. It thus acquires a head greater than the boiler head, due to the added column of water, and is hence able to flow back into the boilers. For small stations the system would appear to

possess substantial advantages, but for large ones the complication would be considerable, and there would be a considerable amount of risk attaching to the connection of so many points together, if any of the non-return valves failed to act, especially if it became necessary to suddenly isolate a section of the range.

The second kind of draining, namely, that of the entrained water, is accomplished by means of 'steam separators.' These, again, are to be found in great variety, but all depend on the greater momentum possessed by water above that of steam. The steam containing water is caused to

FIG. 33A.—Lancaster steam trap.

abruptly change the direction of its motion; the steam having little mass does so readily, but the water impinges on the bafflers and is arrested, dropping down into a vessel provided for the purpose and drained by means of an ordinary trap. The velocity of the wet steam is often checked at the same time by enlarging the passage through which it travels, thus further assisting the deposition of the water. The U-shaped expansion joints described above act to some extent as separators.

Separators are often fixed at the boiler delivery so as to remove water caused by priming and next the engine to remove water of condensation.

The former course is only necessary with a type of boiler that gives wet steam; the latter is to be recommended in all cases, except when superheating is employed.

A more effectual way of dealing with the condensation in steam pipes, and one having a most important effect on the economy of the engines by reducing the condensation in them, is by means of superheating—a practice now being revived after having been almost abandoned for many years, owing chiefly to difficulties experienced through the carbonising of the oil in the engine cylinders, and through the destruction of the packings of the glands. These difficulties can now be obviated in large measure by the use of suitable mineral oils and metallic packings.

Superheating consists in heating the steam to a temperature higher than that corresponding to its pressure, without allowing the pressure to rise. This cannot be done in the presence of water, since the effect would be that the steam would impart the heat producing the excess temperature to the water, and so cause the evolution of additional saturated steam. It is obvious, however, that if the water be limited in amount, the process can only go on until it is all evaporated; and, therefore, if superheated steam be introduced into a steam pipe or cylinder containing water, the effect will be that this water will be evaporated by the steam so long as its quantity is not so great as to require more heat than that held in excess of the normal by the steam. If, therefore, steam be superheated sufficiently, its temperature will not be lowered to so great an extent as even to reach saturation, far less to cause condensation, and all trouble due to the presence of water is avoided.

This effect of superheating, though diminishing waste and obviating much inconvenience, is not the principal feature of the process, the chief economy being found in the saving of condensation in the cylinders of the engine.

Saturated steam is found not to behave as a true gas, but, after 20° F. of superheat has been applied to it, the laws of gases apply so far as present experiment shows. It has also been observed that the rate of fall of temperature of superheated steam from radiation is greater than that of saturated, and this is ascribed to its not containing water particles having heat retaining properties; it would seem that it must be due also to the greater difference of temperature under which the heat is radiated.

The imparting of a portion of the heat of the fuel directly to the steam instead of to the water leads to largely increased efficiency of the boiler, as will be seen from the table on the next page, which summarises some of the experiments published by Mr Patchell.

The percentage gain found by the use of superheaters was from 10 to 12 per cent. to over 30 per cent. in the amount of water evaporated per lb. of fuel.

In order to show the total gain in a central station by superheating, some tests made by Professor Kennedy may be quoted. He found that during two trials, each of twenty-four hours' duration, one with superheating and one without, the saving in steam amounted to about 9 per cent., while the saving in coal amounted to 11 per cent. More accurate tests

Amount of superheat.	Water evaporated per lb. of coal.	
	Without superheat.	With superheat.
40 deg. Fah., ...	7·82	9·99
42 ,, ...	6·42	7·06
55 ,, ...	6·00	7·00
56·5 ,, ...	6·78	8·66
55·2 ,, ...	7·15	8·65

showed that with an average superheat of 70° to 75° F. at the boilers, rising to 80° or 85° F. at full load, and averaging about 65° F. at the engine, the saving was as much as 22 per cent. by superheating, but this dropped to 11 per cent. when the superheating at the engine was 30° F. only.

The cost of superheating is, comparatively speaking, insignificant, and the figures are sufficient to show that it should never be omitted in a central station. In applying it, care must not only be taken to provide high-class oil for lubricating the cylinders, and metallic packings for the glands, as already stated, but extra care must be taken to see that all pistons and valves fit well, since there is more liability to leakage with superheated steam than with saturated. Attention must also be devoted to keeping the amount of superheat constant, for alternation between superheat and saturated steam has a very bad effect on the cylinders, being liable to cause cutting.

The superheat is imparted to the steam in a special piece of apparatus called a 'Superheater'; it is obvious, from what has been said, that superheating cannot take place in the boiler itself, owing to the presence of water.

Superheaters are very simple, and are, in fact, no more than tubular boilers containing steam to be heated instead of water. They are divided into two main classes, viz.: (1) those which are heated by the flue gases from the boilers in a similar manner to economisers; and (2) those which are separately fired.

The first class are those most commonly used, and, of course, are the least expensive in first cost, and involve no extra labour in firing, but they are open to the disadvantage that they do not admit of the amount of superheat being easily controlled. Inasmuch, however, as the more steam raised, the greater the rate at which the boiler has to be fired, and the more

the heat therefore passing up the flues, there is a tendency to maintain the amount of superheating constant. Another drawback to this class is that there is, in many cases, considerable difficulty in getting at the tubes to clean them, and their presence in the flue is inconvenient.

The second class of superheater possesses the advantage that gases as hot as those used in firing the boiler can be used, and so a higher degree of superheat be attained, while the amount is at all times under control. It has, however, the drawbacks that there is a liability to fluctuation in temperature during the process of firing, and it is not so convenient to take the steam through a separate piece of apparatus, while the additional labour in firing must also be taken into account. Gas firing would seem to be particularly well suited for separately fired superheaters.

There is a large variety of superheaters, into the details of which it is unnecessary to enter. They usually consist of a number of small tubes, arranged in parallel, through which the steam is passed. There is no difficulty in keeping the interior of the tubes clean, since, unlike boilers, no scale can be deposited in them. Care is necessary to see that none of the tubes be blocked up, and a bypass for the gases must be provided for use when the steam is shut off from the superheater, as, if no steam passes through the tubes, they are liable to be rapidly burnt out. It is convenient to have means of flooding the superheater when getting up steam, so that it may not be exposed to the heat without steam or water passing through it and also when superheating is not required. When flooded, the superheater merely acts as an addition to the heating surface of the boiler.

We have now to consider the material and construction of the pipes. In the case of low pressures and small pipes, cast iron is sometimes used, but it is not to be recommended. Undoubtedly the best material is steel, the joints being welded, and in large sizes covered with a strap riveted on. Another excellent way of building up a large pipe is to adopt a construction similar to that used in a shell of a Lancashire boiler. The flanges may either be welded on, or else riveted, while smaller pipes may have the flanges screwed on, brazed, and caulked.

The flanges should be accurately faced, and, for large pipes, it is sometimes recommended that a boss, projecting from $\frac{1}{16}$ to $\frac{1}{8}$ of an inch, should be left within the ring of bolt holes, this portion only being used to make the joint; the Author is unable to say if there is any advantage in this.

It is of the utmost advantage to have the pipes in as long lengths as possible, difficulties with leakage being usually met with at the joints, and very rarely in the pipes themselves. With the form of pipe in which the parts are riveted together, as above described, the only limit to the length is that which can be handled, and the Author has lengths of 30 feet and even 44 feet without a single joint.

Where joints occur, they may be made in many different ways. In a well-designed range, where expansion has been properly provided for and the joints are truly faced, the best material to use is probably pure asbestos, either by itself, or, if preferred, in conjunction with copper rings.

Where the expansion stresses, however, are great, and there is a considerable alteration in length of the pipe range with change of temperature, this material has not sufficient elasticity, and it is necessary to substitute something else.

Vulcanised indiarubber of good quality is fairly satisfactory, but the heat, especially with high pressures, tends to over-vulcanise the rubber and render it brittle, and in time the joint loses its elasticity.

Probably the best material where much movement has to be faced is one made by strongly compressing a mixture of asbestos and unvulcanised vulcanising rubber; when subjected to heat, the rubber vulcanises and remains elastic. The mixture is made up into rings, and fine brass wire gauze embedded in it. Two concentric rings made in this way are usually employed, one on each side of a copper ring, stamped so as to bring the two into one plane. In this manner each flange has on its face a ring of asbestos mixture and one of copper, backed up by the mixture on the other side.

An almost endless number of different kinds of jointing materials, made up in many forms, are in the market, but it is unnecessary to enumerate them.

Bends and T-pieces should be of cast steel, but for larger sizes may be built up of wrought steel plates like the pipes.

Each boiler requires a certain number of fittings and mountings. They should be of the best quality obtainable, and should be absolutely uniform throughout the whole system, and all parts be interchangeable. The mountings need not here be enumerated, but a few points concerning them may be noted. One of the most important is, of course, the safety valve, which may, and preferably should, be a simple dead-weight, or, a weighted lever may be employed, while, for very high pressures, spring-loaded valves are sometimes preferred.

Another valve which is usually fixed is a 'high steam and low water' valve. Though invaluable in the case of boilers looked after intermittently by an attendant, it is difficult to see what use these valves are in a central station where stokers are continuously on duty, and, by the very nature of their work, have to eagerly watch the gauge glasses, while the engineer in charge will also have a keen eye to the matter. These valves are perhaps the most unsatisfactory fitting of a boiler, and are constantly going out of order; when once they begin to blow, they rapidly become worse, causing immense waste of steam.

Both the dead-weight and the high steam and low water valves should be arranged to blow off directly into the boiler house, so that any defect may

at once claim attention. If they be connected to pipes led away out of sight, the amount of waste that may go on is appalling.

In the case of a large station, it may be advisable to provide one or two outlets, controlled by ordinary stop valves, so that, in case of a sudden shut down when the boilers are under full steam, especially if they be of a type with large water space and therefore great heat reserve, they may be opened to the atmosphere, and so assist the ordinary safety valves in discharging the steam. Such an emergency may not arise once in ten years, perhaps never, but it is not expensive to provide for it.

Gauge glasses should always be provided in duplicate, and should be fitted with guards, simple plate glass ones being as satisfactory as any.

In boilers such as the Babcock and Wilcox, in which the gauges are, of necessity, fixed at a considerable height above the floor level, those glasses in which, by means of an optical illusion, the water is made to appear of a dark colour are extremely useful.

The stop valves should be of the full-way type, and large sizes should have bypasses to facilitate their operation. The valve covers should be covered with non-conducting composition.

The blow-off taps should be so arranged that they cannot inadvertently be left open, the usual method of securing this being to provide a locking-piece which prevents the key actuating the tap being removed unless the water is shut off.

When working a number of boilers on one range, the utmost care should be taken to avoid a valve being opened on a boiler not under steam. The result of so doing, when men are in the boiler, is too appalling to contemplate. Many ways of avoiding such a catastrophe will readily present themselves; the expedient adopted by the Author—duplicate ranges being in use—is to chain the wheels of the two junction valves together, and to lock the chain by means of a padlock, the key being given to the man at work in the boiler. Similar care must be exercised with regard to the feed valves.

Isolating valves are sometimes employed, their object being to automatically cut off a boiler if it ceases to supply steam. They may be good, but the fewer automatic devices of the kind there are the better.

In conclusion, it may be remarked that complication should be avoided as far as possible, and it will be well to keep clear of most of the well-nigh innumerable nostrums for making more or less imaginary savings of fuel, prevention of smoke, etc.

CHAPTER XV.

GENERATORS.

By the term Generator is to be understood the electrical machine whereby mechanical energy is transformed into electrical energy and the prime mover in which the mechanical energy resides immediately before its conversion.

This definition, it will be seen, is very comprehensive, and, on the one hand, includes dynamo machines of every conceivable variety, whether for producing continuous current or alternating of one or more phases, at low or high pressure; while, on the other, it comprises prime movers of all kinds, whether driven by steam, moving water, gas, or oil vapour.

It is obvious that it is out of the question to attempt to enter either into the theory or practical design of all or any of these machines in a single chapter of a book of this kind. Each item—dynamo machines, steam engines, turbines, gas engines—has a whole literature of its own, and to the standard works dealing with these matters the reader must be referred. It will only be attempted here to deal with a few aspects of the subject from a purely central station point of view.

A generator of electrical energy, as used in central station work, consists of two essential parts, viz.: (1) a prime mover of some kind to furnish the mechanical energy in a kinetic form; and (2) a dynamo machine, driven by the prime mover, and converting the mechanical energy into electrical energy in the particular form desired. There are other kinds of generators depending for their operation on chemical action, as primary batteries, or on the direct effect of heat, as thermo-electric apparatus; but up to the present all attempts to utilise these, on even a moderately large scale, have been entire failures, and, practically speaking, mass in motion is, so far, the link nearest to electrical power in the chain of conversion.

Mechanically, generators may be classified according as they are driven by steam, gas, or water, this being the order of relative importance in this country, though the first and last are practically interchanged in some parts of America and the Continent, while in the near future it is quite likely that the second may overtop the other two.

Electrically, generators naturally fall into the two main divisions of continuous current and alternating current machines.

Yet a third classification may be made according to the method of connecting the mechanical prime mover to the electrical transformer of energy, the classes being two in number, according as the driving is direct or through the intervention of gearing.

Probably the first classification is the most convenient, and the others may be described as subdivisions of one of its main headings, the remarks on them being taken as applicable to other headings, such modifications as they involve being pointed out.

Steam engines display an infinite variety in detail, and can be built to give a wide range of desired results, though a high degree of perfection in one direction may have to be attained by a corresponding sacrifice in another.

The chief essentials for engines for electrical work are the following:—(1) Reliability and freedom from breakdown; (2) steady running; (3) high economy; (4) simplicity; (5) facility for repair; (6) ability to withstand sudden shocks and momentary or prolonged overload; (7) compactness, chiefly as regards floor space, but partly, also, as regards height; (8) small amount of attention required during running; (9) low first cost, so far as is compatible with the above conditions and small cost for repairs.

The reliability and freedom from breakdown of an engine will depend primarily upon its design, *i.e.*, the suitability of the size and proportion of its various parts. This is best secured by employing makers of wide experience and first-class reputation. It is folly for a central station engineer to give a detailed specification of the sizes of the various parts. Let him detail the conditions under which the engine is to work, and the results that must be attained, and leave the design to those who have devoted their lives to this class of work and no other. By interfering and specifying certain leading dimensions, he may spoil the whole design, for symmetry and due proportion are of almost as much importance as the actual strength of an individual part. The Author has known an electrical engineer specify dimensions that to an experienced engine builder were wholly absurd, some parts being below and others above the strength usually allowed under ordinary practice, while parts actually transmitting identical stresses were of widely different sizes. The engineer will, however, of course, insist upon knowing the details of the design, and will exercise his judgment as to its correctness.

A point second in importance only to the general design, in favour of freedom from breakdown, is simplicity. It is self-evident that a piece of mechanism with few parts is far less likely to give trouble than one with many complications. For this reason, it may often be advisable to sacrifice a certain amount of economy to secure the elimination of particular chances of failure.

Steady running is of importance in all cases, but for some work it is a primary essential, as in the parallel running of alternators, and especially in the operation of rotatory converters.

Steady running is of two kinds, viz.: (1) from revolution to revolution, and (2) during a revolution. The former is attained by good governing, the latter, which is the most important factor in alternating work, is secured first by even turning moment and then by the use of a fly wheel having a large amount of inertia.

The necessity for simplicity has already been touched on. It is secured by reducing the number of parts as much as possible, and avoiding complicated gears and automatic appliances.

Facility for repair is dependent chiefly on general design; it implies that any part requiring attention shall be accessible and removable with the minimum of disturbance of other parts.

The ability to withstand sudden shocks depends upon the strength of the elements of the mechanism, this being calculated, not on the normal working conditions, but on the most severe ones that it is apprehended can ever be imposed in case of emergency. The question of overload is chiefly one of size of cylinder; the necessity for meeting it has been shown in Chapter VIII. It is of little importance what the economy is at the overload rate, since the engine only works at this rate for a short time. The normal full load is that at which it should be designed to have maximum economy.

The compactness is important, because the value of the floor space is an important item in the standing charges, involving not only the cost of the land, but of the buildings also, the latter being affected as well by the height of the engine.

The amount of attention required by an engine while running depends chiefly upon the governing arrangements and on the system of lubrication adopted.

Finally, low first cost depends upon the simplicity of the engine, and very largely on the speed; while the amount of repairs required depends on the excellence of the design and the quality of the material and workmanship employed in construction.

With these few preliminary remarks, we may now consider briefly the various types of engine available.

Engines are either single, compound, triple, or quadruple expansion, according as the steam is expanded in one, two, three, or four stages respectively. The necessity for the series of expansions arises from the fact that only a certain ratio of expansion in a single cylinder is economical, and since the efficiency of the machine as a heat engine depends on the difference in the temperatures between which it works, and the initial temperature on the pressure of the steam, it follows

that for high economy a high steam pressure and therefore a number of cylinders must be used.

The difference in economy between single and compound engines is so great that practically the former are never employed; the difference between compound and triple does not, under the most favourable conditions, exceed 10 per cent., while between triple and quadruple the difference is, comparatively speaking, trifling.

In comparing the merits of the various kinds, it must be borne in mind that the saving effected by increasing the number of expansions is on the steam consumption, and on nothing else; while against this must be set the increased capital cost of the engine, the additional complication and liability to breakdown in consequence of the larger number of parts, and the increased friction, which last item alone, it is affirmed by some authorities, is sufficient to counterbalance the gain in economy due to diminished steam consumption.

Now, what is the precise advantage of decreasing the steam consumption? In the first place, less fuel has to be consumed to produce the lessened quantity of steam. This involves a saving not only on the actual cost of the coal, but also on the cost of handling it, firing the boilers, and disposing of the ashes. Next, the capacity of the boilers need not be so great, and a saving is made on the capital cost of the boiler plant, including such accessories as feed pumps and mechanical stokers. Lastly, smaller steam pipes, costing less to provide and wasting less heat by radiation, are required.

The most important saving is obviously on the cost of fuel. In an ordinary central station this amounts to only about 30 per cent. of the total cost of production at the utmost, and in many cases it is far less; hence, the saving of 10 per cent. in the fuel is made on 30 per cent. of the cost only, or, in other words, it represents but a saving of 3 per cent. on the total costs.

In order, however, to effect this saving, which is made, be it remembered, on the fuel consumption per indicated horsepower, the engine must run at or near full load, for the rate of saving diminishes as the load falls off. In a central station, it is well-nigh impossible to secure this, for, with the changing load experienced, it is inevitable that the load on individual engines shall fluctuate. This will happen no matter how carefully the sizes may be chosen, for, as the load grows, the engines at work, which at a given time may have been fully loaded, gradually become overloaded, and when another is put in to relieve them, they all become underloaded. Again, in certain conditions of the weather, it is necessary to run more plant than is actually required, in order to be ready for a sudden rush of demand.

Lastly, as has already been pointed out, the saving is made on the

consumption of fuel per indicated horsepower; when the economy reckoned on the brake horsepower, or the electrical output is considered, the saving may completely vanish.

This matter is one that has engaged the close and anxious attention of the Author, especially in connection with the design of a station of 50,000 H.P., and the conclusion at which he has arrived is that, under ordinary central station conditions, quadruple expansion engines would be quite unsuitable, while the fuel consumption of compound engines per unit of electrical energy generated would not appreciably exceed that of triple expansion engines, and the balance is amply turned in favour of the former by their smaller cost and greater simplicity and freedom from risk of breakdown.

The analogy of marine practice is frequently urged in favour of triple and even quadruple expansion engines for central station work, but the analogy does not hold, for the conditions are wholly different. In marine work, the load being a steady one, the maximum saving of coal can be ensured, and the fuel consumption is the ruling consideration, for, not only is the saving of its cost of great importance, but there is the fact that storage room for the coal has to be found on board the vessel, and every ton saved means so much less dead weight to carry, and so much more space for remunerative cargo.

The advantages of condensing and superheating are referred to elsewhere in this book, and need not be further enlarged on here. By the use of the latter process, the steam consumption of compound engines can be so materially improved as to remove the last doubt about their use.

To sum up the matter, the Author's opinion is that for central station work a compound condensing engine, using superheated steam at a boiler pressure of 160 lbs. per square inch, is the most suitable that can be employed.

The next point to determine is whether the engine shall run at a high speed or at a low one. This point has already been touched upon in Chapter VIII.; and it is one that has been very much debated, but it cannot be said that any definite conclusion can be safely drawn. Practice in this country up to quite lately has been in favour of high speeds, while American and Continental practice has been unmistakably on the side of slow speed. With the introduction of larger sizes of engine, the number of revolutions per minute of the high-speed engine necessarily falls, so that for very large powers they are hardly high speed more than in name, and, even in English practice, there is a tendency to revert to slow speeds.

The term slow speed is usually restricted to engines making not more than 100 revolutions per minute or thereabouts. Up to this speed, Corliss valve gear works well, but it cannot safely be pushed much higher.

When this rate is exceeded, slide valves or piston valves become imperative.

It is claimed by advocates of slow-speed engines that Corliss gear is the most economical that can be employed, that the wear and tear of the mechanism is far less than that of high-speed engines, while, if anything goes wrong, it can be foreseen and either 'nursed' until the run is over or the engine be taken out before actual breakdown occurs. Again, it is easy to provide for a large overload capacity without interfering with the economy at the normal load; and, lastly, the parts are such as can be speedily repaired by an ordinary fitter.

Against these contentions, the advocates of high-speed engines urge that they are practically as efficient as slow-speed, and the amount of attention during running is very slight, while they dispute the statement that the repairs are heavy; on the contrary, they allege them to be much less than those required by slow-speed engines; they deny the necessity for a large overload margin, but admit the fact that if anything goes wrong it does so suddenly and necessitates the engine being taken out of service at once. They urge that the floor space is much less than that required by slow-speed plant, and that the high speed much more nearly approximates to that of the electrical portion of the generator.

There is a large mass of evidence available to support the statements of both parties, and it is difficult to decide between them. It seems to be very largely a question of the size of engine, at all events, as regards a number of points. Thus, for small sizes, a considerable saving in cost is undoubtedly effected by running the dynamos at a high speed, and the saving in floor space is great. The economy of the engines when new is high, and for a considerable time, at any rate, the repairs are light. The attention required during running is very small. Where large sizes are in question, however, matters are changed. The difference in cost is slight, and for very large sizes may even be against the high-speed plant. The floor space occupied is actually less with the slow-speed combination, and the efficiency may be made very high.

When experience extending over the same period of years has been gained with high-speed engines as has already been obtained with slow-speed ones used for other purposes, it will probably be found that the repairs on the slow running plant cost less, and that the high initial efficiency is better maintained.

In the present state of knowledge, the Author would be inclined to say that for all sizes up to 250 kilowatts the high-speed engine is to be preferred; for sizes intermediate between this and, say, 750 kilowatts, the balance of advantage is probably in favour of the high speed, becoming less so as the upper limit is reached; while for sizes above this, recourse should be had to slow running engines.

The above remarks do not apply to steam turbines, referred to below, the field of usefulness of which is only just being appreciated by engineers.

A point of some importance to be determined is whether the cylinders shall be vertical or horizontal. Horizontal engines are undoubtedly more accessible for repairs, and easier to keep clean, but they possess the inherent defect that the wear on the cylinders is uneven and greater than with vertical; while the floor space required is much greater, and drainage of cylinders is less perfect. The Author would pronounce unhesitatingly in favour of vertical engines.

It will be convenient to refer here to the coupling of the engine to the dynamo. There can be no question that the best course to adopt is to build the dynamo to run at the same speed as the engine, and couple them both to the same shaft. The tendency of recent practice is to this, whether the speed be high or low. The advantages are overwhelming: a link in the mechanical chain, and that the weakest link, is dispensed with; the efficiency is increased, both by eliminating the gearing and reducing the number of bearings; the amount of attendance is substantially lessened; and, finally, the floor space is immensely diminished.

By far the best form of direct coupling is that in which the dynamo is placed between the two halves of the engine, the revolving portion being mounted on the same shaft as the fly-wheel, and being mechanically coupled to it, or, in some cases, taking its place. By this method the number of bearings is reduced to a minimum, only two being required. If these be of the spherical form, the alignment is perfect, and, provided the length of each bearing be ample, the friction is very small. The stresses on the shaft are symmetrical, and are of as small value as is possible for an engine of a given power. The engine should be an enclosed one when this system of driving is adopted, in order to protect the dynamo from oil and water.

The alternative to this method is to place the dynamo at one end of the shaft—the course usually adopted when there are more than two cylinders. The drawbacks to this arrangement are that the number of bearings is materially increased, and in consequence the difficulty of perfect alignment, while the whole power of the engine has to be transmitted through the crank nearest the dynamo. There are, however, several advantages which must be set against the defects named. The electrical plant is more accessible for repairs, and the risk of damage from oil and water is reduced—a matter of considerable importance with high-pressure plant—while the electrical connections can be more easily kept clear of the engine and its appurtenances.

In direct coupling, when a fly-wheel is used, it is of the utmost importance to ensure that it and the revolving portion of the dynamo shall act as one mass. To effect this, the fly-wheel should be keyed to the shaft; while

the armature or field magnet, as the case may be, should be bolted to the fly-wheel, and merely rest on the shaft without being secured to it. In this way the danger of breaking the shaft by the torsional stress introduced by changes of load is avoided.

The limit of power of a compound engine, such as the one advocated, is determined by the size of the low-pressure cylinder, and with slow-speed plant this will be in the neighbourhood of 4000 H.P. For larger sizes, the low-pressure cylinder must be replaced by two, having an aggregate area equal to that required. This necessitates three cranks, and destroys the symmetry of the arrangement. Under the circumstances, it is preferable to divide the high-pressure cylinder also, and mount the cylinders tandem, a high and low on each side. In this manner, the range of the two-bearing type is raised to 8000 H.P., which is probably as high as it is desirable to go at the present time for a single generator.

In those cases in which uniform angular velocity is the ruling consideration, there seems no question that the best combination is a three-crank engine, with each crank set at an angle of 120° with each of the other two, and each crank having on it a tandem compound engine. If all three engines be controlled by one governor, each will do the same amount of work as the other two at all loads, and the turning moment will approach very nearly to uniformity. If to this be added a very massive fly-wheel of large diameter, the result will be practically uniform angular velocity.

Such an engine, while securing the main requirement, enables cylinders of reasonable size to be used, even for very large powers, and the simplicity is great, although the number of parts is large. The disadvantages are that it entails the coupling of the dynamo at the end of the shaft, the engine is very high, and all the parts are not easily accessible, while the first cost is somewhat high.

This type of engine is practically universal with high-speed engines, but the drawbacks are diminished, owing to the high speed enabling the size of all the parts to be made much less.

So far, direct coupling only has been referred to, but reference should be made to gearing, even though it be going out of use. The most satisfactory form, where there is ample space, is undoubtedly rope-driving. The chief advantage consists in the subdivision of the risk, it being very improbable that more than one rope will give out and break at the same moment, and the material used for transmitting the power is uniform and of great and constant strength. Ropes are elastic, run quietly, are less liable to slip than belts, and are cheaper in first cost, and very much cheaper in maintenance. The grooves on the pulleys, though roughly V-shaped, should have the sides slightly rounded, so as to prevent the ropes becoming wedge-shaped, and the sides should be inclined to one another at an angle

of from 40 to 45°. The bottom of the groove should be round, and so far away as to eliminate all chance of the rope touching it. The most economical speed for the ropes to travel at is from 3600 to 5000 feet per minute.

The alternative to rope-driving is belt-driving. The chief advantage of this lies in the fact that the distance between the centres of the driver and driven pulley can be very greatly shortened by the use of a jockey pulley riding on the slack side of the belt, without any appreciable loss of power, though with considerably increased wear and tear of the belts. The belt may be made of ordinary leather, of leather links held together by steel pins, of woven leather in which a number of leather laces, extending the whole length of the belt, are woven together to form a belt, or of one of the many substitutes for leather, most of which have canvas for a basis. The chief difficulty in the use of most kinds of belts is the joint. With a link belt this is entirely eliminated, there being no difference between the joint and the rest of the belt. In the other kinds, the joint presents sometimes more, sometimes less, difficulty. The best plan is to scarf the joint, and spread it over as great a length as possible.

The question of fly-wheels is of paramount importance. The primary office of a fly-wheel is to absorb energy during that part of the revolution of the engine that work is being done by the steam, and to give it out during that part when no work is being done by the steam. It does this by the acceleration of its velocity, with consequent increase of kinetic energy when work is being done upon it; and by its retardation when the wheel is giving out work, its kinetic energy being thereby diminished. It is obvious that the more mass there is in the wheel, the less need be the alteration in velocity to absorb or give out a given quantity of energy. Thus, for a given arrangement of cranks and diameter and speed of fly-wheel the greater the mass of the wheel, the more uniform the angular velocity.

Apart from the function above described, the fly-wheel is useful as providing a store of energy that is available to meet any sudden excess demand for power extending over several revolutions of the engine, enabling it to deal with momentary overloads, which it would otherwise be powerless to cope with. Similarly, if a large load be thrown off suddenly, the presence of a heavy fly-wheel will require so much work to be done to accelerate it that the speed will be prevented from rising to a dangerous extent.

It is of vital importance that fly-wheels should be so constructed that they will not only resist the stresses they normally have to bear, but also those greatly in excess of these which may be brought into play by an increase of speed due to some mishap.

Except for small sizes, wheels, wholly of cast iron, cannot be recom-

mended for electrical work. Not only is it impossible to entirely eliminate the casting stresses, but the material is ill-adapted to stand the working forces.

The rim should be built up of a number of blocks of cast iron, securely held together by steel or wrought iron cotters or other suitable ties. It should be so constructed that it will by itself sustain the whole of the bursting stress, due to centrifugal force, that may come upon it; and the factor of safety used in calculating the size of the parts should be not less than 10, the conditions for which the forces are worked out being those obtaining when the speed is from 10 to 15 per cent. in excess of the normal.

No account should be taken of the strength due to the tension of the arms for holding the rim together, but these should be made strong enough to pull the rim up in not more than one revolution when running at full speed. The arms may be made of cast iron, securely cottered into the central boss, wrought iron bolts passing through them to take tensional stresses.

Great care should be taken to accurately balance the wheel for the normal speed, and to keep it absolutely true on the shaft.

A particular form of fly-wheel, which has not yet been greatly used, should be specially referred to. In this the arms and rim are replaced by a number of steel plates securely riveted together to form two solid circular plates extending from the central boss to the periphery, the surface of each forming a very blunt cone. It is practically impossible that such a wheel should burst, and, there being no independent arms or rim, the two cannot separate from one another. The only drawback is that the arrangement is unsightly, and, owing to the absence of spaces, blocks up the view of the engine room to a very inconvenient extent.

No matter how carefully a fly-wheel may be built, it is highly dangerous to allow its speed to rise greatly above the normal, and therefore the ordinary governor should not only be provided with a means of instantly checking the speed before it becomes dangerous, but an auxiliary governor should be fixed to effect the same purpose, if the ordinary governor should fail. The second governor should be placed in a different part of the engine, so as to reduce the chance of the same cause that disables the ordinary one damaging it also.

In order to effectually stop a condensing engine from which the whole load has been suddenly thrown off, and which has begun to race, it is necessary, not only to cut off the steam, but also to break the vacuum thoroughly.

There are a good many devices for effecting this object, but it is unnecessary to do more than refer to the best known, namely, Tate's Electric Stop motion, which is very extensively used for the purpose in mills. In

this the ordinary stop valve, when opened, winds up a powerful spring, which is held by a catch while the engine is at work. A small auxiliary governor makes an electrical contact if the speed rises above a predetermined value, and actuates a relay which trips the catch, releasing the spring, which then closes the stop valve, the vacuum being at the same time broken.

Although by some such means it is possible to safeguard the fly-wheel, it must not be forgotten that the sudden shutting down of a generator may produce most serious results when several are running in parallel on the circuit; and even though the use of a minimum cutout may prevent the other machines being short-circuited, yet the excess load suddenly thrown on them may play havoc with the supply. For this reason, automatic appliances of the kind named should be used with extreme caution; and if the wheels be built with a very large margin of strength, it may be safer to take the risk of an increase in speed.

The ordinary governor of the engine is one of its most important features. To enter into a description of the various forms in use would be foreign to the intention of this book; it is only necessary to point out the objects to be sought.

In the first place, the governor should be able to take charge of the engine at all loads, with the main stop valve full open. This is an important factor in preventing racing of the engine, in the event of the load being thrown off suddenly, and greatly diminishes the amount of attention required by the engine when running.

The governor should be sensitive, but must work steadily without hunting, and should keep the speed constant within, say, 2 per cent. at all loads for continuous current machines, or, say, 4 per cent. for alternators. It should, however, be so arranged that it can be adjusted by hand while running, so that the speed of the engine may be altered at will, the governor again taking charge and maintaining the new speed constant within the same percentage.

The governor should be fitted with an arrangement for knocking off the engine by shutting off the steam and breaking the vacuum, if a dangerous speed be attained, in addition to the emergency governor. It has been proposed to so arrange the governor that in the event of its being carried away from any cause, the engine shall be automatically shut down. Such a course has much to recommend it, if the mechanism can be so made as to eliminate all risk of its acting when not required.

In place of actually shutting off the steam, the arrangement is sometimes made to throttle the steam and merely reduce the speed of the engine. Under some conditions, this is no doubt the better plan; but, seeing that the vacuum alone is sufficient to keep the engine running at full speed, if the load be wholly absent, it cannot be regarded as affording such absolute security as cutting it off completely.

FIG. 34.—1200 H.P. Willans Engine.

FIG. 34.—1200 H.P. Willans Engine.

The governor may be driven either by spur or bevel wheels, by chains or by ropes. Perhaps the safest method is the last, several being provided, and any one being sufficient to do the work. Ropes have stood the test of time on a large variety of engines: they give warning in the event of wear, do not break easily, they share the work evenly among them, and, lastly, if one break it is not likely to cause any damage.

There are two methods of governing, namely, by throttling the steam and by varying the amount of expansion. The controversy over the relative merits of the two has been long and heated, and the most eminent authorities differ in their opinion. The reader is referred to treatises on the steam engine for a discussion of this point.

In order to reduce the evils of condensation, the cylinders should be steam-jacketed, and it is strongly advocated by some to reheat the steam on its passage from the high to the low pressure cylinder, though the efficacy of this is extremely doubtful.

Having glanced hastily at some of the main points in connection with the engines, a brief reference may be made to a few of the leading types specially designed for central station work.

One of the most widely used and deservedly popular of these special types is the Willans engine. This is essentially a high speed engine, running at from 900 to 250 revolutions per minute, according as the size is small or large. The cylinders are vertical, and are arranged tandem, the high pressure being at the top. The engine is single acting; and in the larger sizes there are three cranks, each crank having its own set of cylinders. Piston valves are used, and are placed within the piston, which is hollow. A 1200 H.P. Willans engine is shown in fig. 34.

Examples of double acting high speed engines which have come into very large use are the Belliss and the Browett & Lindley, but considerations of space preclude a description of these.

Another high speed engine that is meeting with some favour is the 'Universal' engine. In this two cylinders are arranged tandem, and each is single acting; but, inasmuch as one is operative on the downward stroke and the other on the upward, the engine itself is double acting. An example of this engine is shown in fig. 35.

A type of great novelty which is meeting with much success is that invented by Mr Ferranti. It occupies an intermediate position between the high speed engines just described and slow speed ones, combining many of the advantages of both. The speed ordinarily adopted is 250 revolutions per minute, which admits of a moderate size of dynamo, and, for alternating work, facilitates the attainment of even turning, while, by a most ingenious arrangement, the valve gear only moves at half the speed corresponding to the number of revolutions of the engine; the 250 revolution plant being thus equivalent, so far as the valve gear is concerned, to an ordinary engine

Fig. 36.—1500 K.W. Ferranti Alternating Current Generator.

125 revolutions per minute. A 1500 kilowatt alternating ·rator of this type is shown in fig. 36.

·entative example of a slow speed Corliss engine direct coupled ·kilowatt continuous current dynamo is shown in fig. 37; this ·t 100 revolutions per minute, the engine is by Messrs Musgrave, ·namo by the Electric Construction Co.

· of steam engine in which the motion is purely one of rotation ·e use of any reciprocating parts, is the steam turbine. In this the ·es from a number of orifices, and, either by its impulse upon a ·lades, or by its reaction on emergence, causes rotation of the shaft. ·bines, to be efficient, must run at an exceedingly high speed; the ·ntial velocity necessary, for example, with steam at a pressure of ·per square inch, being some 2000 feet per second. For this reason, ·er of revolutions is usually 10,000 and upwards per minute. The · examples are the Parsons and the Laval.

·e Parsons steam turbine, the steam flows radially outwards through ·evolving vanes, and on reaching the outer edge is guided back to the · another set and so on, a large number of sets being employed, all · on one shaft. The action is partly one of reaction and partly of

· Laval steam turbine, unlike the Parsons, depends entirely upon ·. The steam issues from a number of nozzles, and acquires, in ·ing mouthpieces, the full velocity due to its head. It impinges on ·nes of a single simple impulse turbine which revolves at some 30,000 ·tions per minute.

·th types of turbine give excellent results as regards steam consumption, ·ey possess the advantages of requiring small floor space and having ·orking parts; above all, however, they give complete immunity from ·ion, and it is this feature chiefly which has led to their use for central · work.

·eaving steam driven plant, gas engines next claim attention. Theoreti·, an internal combustion engine, in which the energy in the fuel is ·tly transformed into kinetic energy without the intervention of the ·m boiler, is highly attractive. Practically, however, there are many ·wbacks. The first cost of the plant is high, the repairs are considerable, ·diness of driving is far from satisfactory, and the power of a single ·gine is very limited. These drawbacks have led to such gas-driven gener·rs as have been put down meeting with but little success; but there is ·idence that some at least of the disadvantages are being overcome, and, ·fore long, engines of large power, giving very fairly steady turning, may be ·oked for. If these expectations are fulfilled, it is extremely likely that ·onsiderable changes in central station practice may take place, for a gas engine meeting the conditions of this work in a thoroughly practicable and

satisfactory manner would enable the advantages of gas producers and recovery plant indicated in Chapter XI. to be fully realised.

The results attained with a gas engine driving a dynamo developing about 90 H.P. when run, practically continuously, with Mond producer gas, are most interesting. The plant ran for 8356½ hours in the year, *i.e.*, for 95·4 per cent. of the possible number of hours; and under these favourable conditions the consumption of gas was 114·4 cubic feet per unit, corresponding to 1·76 lbs. of slack. Taking slack at 6s. 10d. per ton, the cost per unit is given at 0·066d. for slack, 0·051d. for labour, and 0·030d. for oil and stores. These are, of course, three items only of the whole cost, and the conditions are totally different from those obtaining in a central station.

Practically all modern gas engines work upon the Otto cycle, which occupies two complete strokes. The first outward stroke draws in the explosive mixture, the first inward stroke compresses it, the second outward stroke is the working stroke, the mixture being then ignited, while the second inward stroke expels the products of combustion. There is thus only one impulse in two revolutions, and the driving is therefore very unsteady. This unsteadiness is still further aggravated by the usual method of governing, which consists in omitting a certain proportion of the explosions as the load diminishes.

In the most modern development of the gas engine, viz., that made by the Westinghouse Co., the governing is effected by varying the proportion of the gas in the explosive mixture, instead of the number of explosions. By this means, and by arranging a number of cylinders to actuate the shaft, the running has been made so steady that the dynamo can be directly coupled, as with steam plant, and generators up to 1500 H.P. have been made. A 650 H.P. direct-coupled continuous-current gas engine driven set is shown in fig. 38.

The remaining agent for actuating prime movers that has been mentioned is running water. For central station work, turbines are practically always used for rendering the power available.

A turbine consists essentially of a fixed casing, containing guides to direct the water in the desired direction, and a number of curved blades mounted on a shaft, which they cause to revolve by receiving the water, and causing it to so alter its direction that its energy is expended in causing them to move.

Turbines fall into two main classes, according as there is or is not a pressure of water in the space between the moving vanes and the fixed guides. The former are known as 'Pressure' turbines, and require to be continually filled with water, working best when 'drowned'. The second class, or 'Impulse' turbines, require that the passages between the vanes and the blades should not be filled with water, and the water need not therefore be admitted round the whole circumference. Such turbines cannot be drowned.

A third class is a combination of these two, the design being such that, though the space is filled, there is no pressure, and the passages have the form of the stream that would issue from an impulse turbine. Turbines

FIG. 38.—650 H.P. Westinghouse Gas Engine driven Continuous Current Generator.

may be further subdivided, according as the flow is (1) radial, whether inward or outward, or (2) axial.

The governing of turbines is effected in various ways. In the pressure type, three are available, viz.: (1) By varying the pressure of the water by throttling the admission; this is inefficient, because it destroys part of the

available head. (2) By closing some of the passages; this causes inefficiency by setting up eddies and variable action on the vanes. (3) By altering the area of all the guide passages simultaneously; this is by far the most efficient. In the impulse type, since the efficiency is but little affected by closing a portion of the guide passages, this method is usually adopted, and they are thus much more easily controlled than are those of the pressure type.

The speed regulation is very poor, on account of the large amount of work that has to be done to vary the controlling devices, and there is great tendency to hunting.

The efficiency of turbines may reach from 80 to 85 per cent. under favourable conditions. The type to be adopted depends on the conditions of the fall. For moderate falls, with an ample and steady supply of water, the pressure turbine is usually employed, and is the cheapest. If, however, the supply is variable, or the water descends from a great height, the impulse turbine is the most suitable; in the former case, because of the greater simplicity and efficiency of the regulation; in the latter, on account of its being possible to avoid an excessive speed. Since this type will not work when drowned, it cannot be used if the tail water be subject to variation in level; when this precludes it from being used, and the conditions otherwise demand an impulse turbine, the third kind described, which is a combination of the impulse and pressure types, should be substituted, as it will have the highest average efficiency.

With this very superficial glance at the prime movers available, we may now turn to the electrical portion of the generator.

With continuous current plant, bipolar machines present many advantages, but the limit of their capacity is soon reached, viz.: at about 250 kilowatts. Up to this size a better or cheaper combination can hardly be found than one of these machines directly coupled to a high speed engine. For larger generators, multipolar machines must be resorted to; and for moderate sizes, direct connection to high speed engines is still probably the best, but for capacities of 750 kilowatts and over, it is preferable to arrange the machine for direct connection to slow-running engines, as already pointed out.

It may be taken that, except in very small stations, the size of generator required will be such as to call for multipolar machines. Under all circumstances, and particularly when the load is a varying one, it is preferable that the armature should be slot or tunnel wound. Not only is this better electrically, but the construction is much stronger mechanically, and is usually adopted.

Owing to the necessity for commutating the current, the armature is always the part that revolves. The magnets usually take the form of a cast steel ring, with pole pieces projecting radially inwards. The magnetising coils should be wound on formers easily removed and replaced, and the ring

be arranged either to slide in a direction parallel to the axis of the shaft or to split into two halves, which can be drawn away in a direction at right angles to the shaft, the object in both cases being to give access to the armature.

The most vital part of the machine is the commutator. In a generator of considerable power this is of very large size, and forming, as it does, so integral a part of the machine, it is a most serious matter for it to require repair or renewal. For this reason alone, it is essential to keep down the sparking on its surface as far as possible, so as to reduce the wear to a minimum, and the radial depth of the commutator segments should be made very ample.

The sparking is dependent primarily on the design of the machine, but even if this be good, faulty brush gear may cause violent and destructive flashing. Carbon brushes are to be preferred to copper, and they should be so supported that they are perfectly free to adapt themselves to any variations in the surface of the commutator while preserving a steady and uniform pressure. To this end, their supports should be flexible and very light, aluminium being the most suitable material; and each brush should be so arranged that it may be independently adjusted, and, if necessary, removed while the machine is running. The supports should be short, so as to embrace as small an arc of the commutator as possible, otherwise there may be danger of a local short circuit being established.

The conductors connecting the various sets of brushes together should be so disposed that neither of them is in close proximity to the brush pillars of opposite polarity. These conductors should preferably be continuously insulated, as the presence of two bare rings close together, and differing in potential by the full pressure of the machine, is dangerous on account of the risk of accidental short circuit, and the possible establishment of arcs if there be violent rushes of current on the occurrence of external short circuits or similar disturbances.

The brushes, as a whole, must be provided with rocking gear, although machines can be obtained that are guaranteed not to require any shifting of the brushes between no load and full load. This arrangement, even though not required for changes in load, is useful for moving the brushes into a convenient position for cleaning or adjustment when the machine is at rest.

For lighting, and for traction when batteries are used for steadying the load, the generators are usually shunt-wound. For ordinary traction use, however, they are generally compounded, or, for long lines, over-compounded.

A very convenient machine is one that will give the lighting pressure as a shunt machine and the traction pressure as a compound.

High pressure continuous current machines have been built for pressures up to 2000 and even 2500 volts, and are said to give satisfactory results; but it is obvious that the difficulties ordinarily met with in the commutators

of low pressure machines must be greatly magnified, while the difficulty of properly insulating and keeping insulated the high pressure winding, when subjected to the stresses incidental to being revolved, is very great. In the event of the commutator flashing round, or an armature burning out, the machine has practically to be rebuilt, and it is impossible to arrange for its speedy repair.

Alternating current generators have the enormous advantage that they require no commutator, and, in consequence, the construction is greatly simplified, the cost reduced, and the wear and tear diminished. At the same time, it becomes possible to fix the armature and revolve the field magnets, thus in a high pressure machine greatly facilitating and rendering more safe the insulation of the conductors. Whether fixed or revolving, the armature lends itself to the adoption of a construction whereby a damaged coil can be easily and speedily replaced.

The excitation of generators is a most important matter. With continuous current plant, each machine may be self-exciting, but with alternators this is obviously impossible, while, with either class of plant, separate excitation may be used. Again, with continuous current plant, the variation in pressure of the machine and increase in exciting power may be effected by increasing the speed of the machine, or by altering the resistance in the exciting circuit; while, with alternating plant, the former expedient cannot be adopted without interfering with the periodicity.

For continuous current work, the Author has found self-excitation thoroughly satisfactory, and the simplicity and security are strong recommendations. It is more convenient to vary the exciting power by means of an adjustable resistance than by altering the speed, and it admits of the whole of the regulation being done by the switchboard attendant. It, of course, introduces much greater risks of accidental opening of the magnet circuit, and precautions must be taken to see that all contacts on the regulating switch are kept thoroughly clean, and the resistances themselves in good order; several coils in parallel should in all cases be used. With the greatest care, however, there is a possibility that the field circuit may become opened, and the means taken by the Author to avoid the disastrous results that would ensue in the case of two 1500 kilowatt continuous current generators may be of interest. Across the terminals of the shunt winding on the machine itself is connected a resistance having a value equal to that normally in series with the field winding when the machine is fully loaded. This resistance is controlled by a switch that is held in the off position by the current passing through the ordinary resistance and regulating switch. When the current through this falls to a certain value, the switch is released and closes the circuit through the standby resistance, thus completing the field circuit through it, even before the current can have been interrupted by the rupture of the ordinary circuit.

For alternating current work, each machine may be excited from its own separately driven exciter, or all the generators may be excited in parallel from omnibus bars.

In the former case, the exciter is usually driven from the shaft of the generator, and the two machines stand or fall together, but involve the excitation of no other machines, if anything goes wrong.

In the latter case, a few efficient exciters suffice, or accumulators may be used, but anything going wrong with the exciting current affects the whole station.

The merits of the two systems have been much debated, without any unanimous decision being arrived at. On the whole, the Author would incline to the former.

Seeing how vitally important is this matter, it might be worth while to have a separate exciter to each machine, and a battery as a stand-by, of such a capacity as to suffice for, say, two machines. An arrangement somewhat similar to that described for the continuous current machines could be made to automatically switch on the stand-by, if the ordinary exciter failed, or there might be two main independent sources of excitation, from either of which any generator might be excited.

As regards the mechanical details of the generator as a whole, perhaps the most important question is that of lubrication. There can be no doubt that the most effectual method is by means of oil pumped under pressure in considerable volume through the bearings. The pumps should be in duplicate, and be worked from the main engine; they should give a pressure of about 40 lbs. per square inch, and the pipes leading to the various parts should be of ample area. The oil, after passing through the bearings, should be returned to the pump through a filter. The use of this system necessitates the enclosure of the working parts, and very careful arrangements to retain the oil and prevent it from spurting over the electrical part of the generator; this, however, presents no great difficulty.

In single-acting engines, it is usual to employ what is known as the 'splash' system of lubrication, the cranks revolving in a chamber partially filled with oil; as the crank comes round, it becomes submerged, and, as it strikes the surface, throws up the oil in the form of spray.

The lubrication of the cylinders should be effected by means of sight-feed lubricators, which should be in duplicate. It is preferable to take the oil delivery into the steam pipe at a point just before the steam enters the cylinder.

The staging should be such as to give ready access to all parts of the generator, and should be sufficiently strong to bear the weight of fairly heavy parts during overhauling. At the same time, it should be so arranged either that it offers no obstruction to getting at the armature for overhauling, or that it can be readily removed for the same purpose.

CHAPTER XVI.

CONDENSING APPLIANCES.

THE primary object of condensing the exhaust steam from an engine is to increase the range of temperature between which it works. By reducing the temperature, it lowers the pressure against which the steam is exhausted, replacing the pressure of the air with that of the saturation pressure of the steam. It has been found that the effect of the condenser is produced on that portion of the steam consumption which is not dependent on the power developed, *i.e.* that used in overcoming the friction of the engine, cylinder condensation, radiation, etc. From this it is evident that the importance of condensing increases as the load on a given engine diminishes, the saving made by the condenser varying from, say, 18 per cent. at full load to nearly 60 per cent. at a very small load. From the saving due to the condenser must, of course, be deducted the cost of providing and working it.

There are other advantages attendant on the use of a condenser, which, though theoretically of less importance, are in practice as great. The condenser obviates the noise and vibration caused by atmospheric exhaust, and prevents the spray caused by the partial condensation of the exhaust steam when discharged into the air. The nuisance so produced is very great, and often gives rise to serious trouble.

With some types of condenser there is a substantial saving made in the consumption of water, since they allow of the same water being used over and over again for boiler feeding. Not only does this economise water, which in itself is a great gain where it has to be purchased from the town mains, but the water, being distilled, is pure and free from air, while the quantity of heat retained by it represents the saving of a substantial amount of fuel.

A condenser has, then, two main duties to fulfil: it must cool the steam, and at the same time exclude air from the chamber into which it is exhausted.

There are various kinds of condensers, but all fall broadly into two classes, viz.: (1) those in which the condensing water mixes with the steam to be condensed; and (2) those in which the admixture is not made, the action taking place through conducting walls.

The first-named class has the advantages of simplicity, low first cost, and convenience; but, unless the condensing water is suitable for boiler feed, it necessitates the wasting of the condensed water, and, in any case, the loss of the greater part of the heat. Also the vacuum attained is lower than with the other class.

The second group of condensers are much more expensive in first cost, in maintenance, and in running; but they give a higher vacuum, enable the condensed steam and the whole of the heat it contains to be utilised, and, incidentally, they afford a ready means of testing, when desired, the steam consumption of the engines to which they are attached.

The class in which the water is mixed with the steam comprises the Jet, the Ejector, and the Barometric.

The Jet condenser is one of the oldest, and is but rarely used for central station work. It comprises a chamber to which the exhaust is connected and into which water is introduced in the form of a fine spray. The water so injected, and whatever air may have been entrained in the steam, are removed by means of an air pump.

The Ejector condenser is one that has met with much favour for central station work, on account of its great simplicity, cheapness, compactness, and reliability.

The Ejector condenser is made in several forms, but all depend on the water being introduced as a solid cylindrical jet into the vacuum chamber connected with the exhaust. The requisite form is given to the water by means of a long cylindrical tube, trumpet-mouthed at both ends. The steam is introduced on to the external surface of the water by means of a number of oblique holes in the tube, and is condensed, imparting its momentum at the same time to the water. The air contained in the steam is removed with the condensed steam by the water. The water may be supplied under a certain head, or the whole of the momentum may be supplied by the steam, according to the circumstances under which the condenser is used.

For an irregular, or frequently varying, load, it is necessary that the water should have a head of not less than 15 feet; and this type of the ejector condenser, being the one best adapted to the needs of central stations, is the only one that need be described.

The condenser is of fixed capacity, which must be that necessary for condensing the steam used by the engines at full load; and, inasmuch as the head is capable of giving the water sufficient velocity without the help of the steam, it can be started before the engine, and so provide a vacuum at once. The vacuum will be thus practically independent of the load, but will fall slightly as that increases.

A fall of not less than 1½ feet from the bottom of the condenser to the level of the discharge is required, and the discharge pipe must be taken

below the surface of the water. The exhaust pipe from the engine should have a gradual fall, and a non-return valve is fixed in this pipe as near the condenser as possible, the object being to prevent the risk of water being accidentally drawn into the cylinder.

The water may be supplied directly from a pump or from a tank into which the pump discharges. The latter is greatly to be preferred, as not only does it provide a reserve in the event of the pump failing, but it allows much of the air thrown by the pump to escape before the water enters the condenser. When centrifugal pumps are used this is especially necessary.

These condensers are most valuable for moderate powers, up to, say, 500 H.P., or rather higher; but for large powers they are not so satisfactory. They require the water to be as cold as possible, a few degrees increase of temperature causing a substantial fall in the vacuum produced.

The Barometric condenser consists of a vacuum chamber into which the exhaust steam is introduced at the bottom; while the condensing water enters at the top, being pumped in by means of a circulating pump. The vacuum chamber has attached to its bottom a pipe not less than 34 feet long, and dipping below water at its base. This tube being taller than the column of water which the air will support, the mixture of steam and water falls down it by gravity. The air entrained in the steam rises to the top of the condenser, and is removed therefrom by means of an air-pump, which need not be of large size, since, unlike that used with the jet condenser, it has only air, and not water, to remove.

The Author has had no experience of this condenser, but it would appear that it is simple, and should not be costly to work, since, once started, the pump has merely to lift the water through the difference in height between the top of the condenser and the barometric height of the water, *i.e.*, only some ten feet. It is obviously rather less convenient than the ejector condenser, and it requires the addition of the air-pump. It is claimed that it requires less power to work than any other type of condenser; that for a given vacuum the temperature is higher, and less condensing water is required; that there is no possibility of water entering the cylinder; that the vacuum attained is higher than with other jet condensers; and that the air being moved from the coldest part necessitates the handling of a smaller volume of air by the pump; and, lastly, that the capital cost is low.

Turning now to the second class, we find that it includes the Surface, the Evaporative, and the Dry Air condensers.

The Surface condenser comprises a chamber into which the steam is exhausted, and through which a number of thin brass tubes pass. A circulating pump keeps up the flow of water through these tubes, while an air-pump connected with the chamber removes the condensed steam, together with any air that may have come over with it from the boilers or have leaked

into the condenser. The water discharged by the air-pump has a temperature of from 110° F. to 130° F., and the excess of this above that of the atmosphere is a measure of the heat returned to the boilers.

In some cases, the steam passes through the tubes and the water round them, the principle, however, remaining the same.

Inasmuch as heat has to pass through the substance of the tubes, there must be a difference of temperature between their walls; and the condensed water is, therefore, about 20° F. above the temperature of the condensing water, so that more water will be required to effect the condensation.

The Evaporative condenser is a surface condenser, in which the tubes are very greatly increased in size; instead of being immersed in water, they are exposed to the air, while a comparatively very small quantity of water is allowed to trickle over the surface of the tubes, and to dissipate the heat by its evaporation.

While retaining the main advantages of the ordinary surface condenser, this condenser is open to several serious drawbacks, notably, the enormous space required, and the great distance from the engine at which it has in consequence to be placed, the long pipes entailing great risk of leakage. The steam arising from the evaporation is very objectionable in many situations, and is nearly as troublesome as if the engines were working non-condensing. The only case in which such a condenser would be considered is that of dearness or scarcity of condensing water, and even then its use does not appear to have been attended with much success.

The Dry Air condenser is one that has been proposed, though it has been but little used, if at all. It is in effect an evaporative condenser without any water. The surfaces are very much greater, and radiation and convection currents in the air are relied upon to dissipate the heat. On the whole, it would probably be better to make no pretence of condensing than sink money in such a contrivance.

When engines are worked non-condensing, it is a common practice to utilise a portion of the waste heat to warm the feed water. Although not condensers, properly so-called, feed-water heaters may conveniently be referred to here. They are, in effect, surface condensers, having a cooling surface very much less than is required to effect condensation of the whole amount of steam, the surface being only from 1 to 2 square feet for every 30 lbs. of feed water pumped per hour. No air-pumps are provided, while the circulating pumps are replaced by the boiler feed pumps. This class of apparatus, although giving little or no vacuum, effects an immense saving of heat, and, when economisers are not used, serves the useful purpose of relieving the boilers from the stresses caused by cold feed, besides depriving the water of much of its hardness. The heater may either be

placed on the suction or the delivery side of the pump. In the latter case, it will, of course, be under pressure, in the former not. Heaters, when used with small auxiliary engines, do something to mitigate their low efficiency, and they are especially to be recommended for use with steam feed pumps.

Having briefly examined the chief kinds of condensers, we may now consider their relative advantages, together with their general arrangements.

The first point to determine is whether each engine should have its own condenser, or whether one condenser should be common to a number of engines. This necessarily depends to some extent on the size of engine, and on the type of condenser. Unless the engines be very small, undoubtedly a separate condenser to each gives the best results, since, by this means, the length of the passage from the cylinder to the condenser is reduced to a minimum, and therewith the risk of leakage. If ejector or jet condensers be employed, there is no difficulty about this, however small the engine, but with surface condensers the cost may be prohibitive. In the case of very large engines of, say, 3000 H.P. and upwards, it is wise, in the opinion of the Author, to subdivide the condenser into two halves, so that, should one set be disabled, it is still possible to obtain a very fair vacuum.

The next question is whether the circulating and air pumps (if the condensers be of a type to require the latter) shall be driven from the engine, or independently of it. This will depend in large measure on the speed of the engine. If this is greatly in excess of 100 revolutions per minute, it is not desirable to take power directly from the engines, since the pumps are best worked at a moderate speed; but for slow speed engines it is certainly cheaper in first cost, and more economical in steam consumption, to run, at all events the air-pump, directly from the main engine. There is, of course, the objection that the engine cannot have the advantage of the vacuum at starting, but this is not a sufficiently serious drawback to outweigh the advantages of this course. The circulating pumps in any case are probably best run separately.

When separately driven, the pumps may be worked either by motors or by steam engines. There are many very compact arrangements of circulating and air pumps steam-driven, some arranged to work compound or even triple-expansion, and themselves condensing, and, when this is the case, they are no doubt very economical; but, on the whole, the Author is of opinion that the simplest and most convenient course is to use centrifugal pumps, driven by motors, for the circulating water, and, if any way possible, to drive the air-pumps from the main engine; for large engines, the circulating pumps should certainly be subdivided into two.

The cost, floor space, quantity of condensing water per lb. of steam condensed, cooling surface, power required for driving, and vacuum obtained,

are given in the following table, which is based, partly on figures given by Mr J. F. C. Snell, and partly on the Author's experience :—

Type of Condenser.	Cost per E.H.P. including Pumps.		Floor Space per E.H.P.	lbs. of Water per lb. of Steam Condensed.	Cooling Surface per lb. of Steam Condensed.	Power Required.	Vacuum. Inches.
	Steam Driven.	Motor Driven.					
Jet,	...	£0·88	...	...	...	2%	...
Ejector,	...	0·9	...	37 lbs.	...	...	22 to 27
Surface,	£1·6	3·75	0·03 sq. ft.	25 lbs.	1·75 to 2 sq. ft.	3%	...
Evaporative,	...	1·8	0·15 sq. ft.	$1\frac{1}{2}$ lbs.	2·75 sq. ft.	2%	20 to 25

The quantity of water required for condensing is obviously very great, but the saving in feed water effected may quite balance this in many cases. Where a plentiful supply of water cannot be had, some method of cooling and re-using the water must be adopted.

The oldest and simplest method is to return the water to a pond, and allow the water to part with its heat naturally to the air. Cooling takes place by radiation, conduction, convection, and (chiefly) by evaporation.

The rate of cooling by radiation will depend on the excess temperature of the water above that of the air, and the clearness of the atmosphere; dissipation of heat by conduction and convection will depend upon the wind; the amount got rid of by evaporating the water will depend on the dew point of the air, the atmospheric pressure, the temperature of the air and of the water, and the removal of the air as it becomes saturated.

Obviously, what is required is a pond having as great an area as possible, while the capacity of the reservoir must be such as to enable a sufficient quantity to be stored to allow the cooling time to take place. The area of surface should be about 2 square feet, and the capacity about $10\frac{1}{2}$ cubic feet, per pound of steam condensed per hour.

The cost of this system of cooling is very high, and, where land is dear, prohibitive. For a concrete pond alone, without allowing for the cost of land, the cost of construction may be taken at about 3s. 9d. per pound of steam condensed per hour. The cost is, however, wholly one of interest charges, since the water returns to the pond by gravitation, and the cost of upkeep is practically *nil*.

Considerable economy of space may be effected by pumping the water at a pressure of from 10 to 20 lbs. per square inch into a series of pipes, whence it escapes through nozzles in the form of fine spray, falling then into a pond. By this means a very large surface is exposed to the air, thus promoting evaporation, but the air rapidly becomes saturated, and so full advantage cannot be taken of this increased surface, while radiation is hindered by the clouds of vapour formed.

The next improvement is to pump the water to a height of from 15 to 20 feet, and allow it to trickle down over a number of plates, sometimes consisting of sheets of corrugated iron, sometimes of wooden strips placed vertically, alternate sets being at right angles to one another. By these means the passage of water is very slow, and the heat it parts with induces a circulation of air through the apparatus. The floor space occupied is only about one-tenth of a square foot per pound of steam condensed per hour.

All these systems necessarily cause a large amount of spray and vapour to be discharged into the air, and hence may cause considerable nuisance. In order to avoid this, and to reduce the floor space to the smallest possible amount, the last-named method has been developed into the cooling tower, in which the vapour is discharged from the top of a tall tower, like smoke from a chimney, and a powerful draught is often maintained by means of fans.

One form of such cooler consists of a number of rectangular laths placed horizontally and transversely within an enclosing chimney up which the heat of the water causes a draught. The water to be cooled is pumped into a trough, about 23 feet above the ground, whence it falls through the cooler. This cooler occupies less than one-twentieth of a square foot of floor space per pound of steam condensed per hour.

When a fan is used to increase the draught, the tower can be made much higher, and the floor space correspondingly reduced, less than one-hundredth of a square foot sufficing for each pound of steam condensed per hour.

The cooling and distributing surface is, in some cases, formed of wood, enclosed in a wooden chimney; in others of earthenware; and in others, again, of metal gauze, the containing vessel in these two latter cases being of wrought iron.

The fan is usually placed at the base of the tower, but sometimes at the top, in which case the draught is an induced one.

The power taken to drive the fans will be about 3 per cent. of that developed by the engine, the steam from which is being dealt with; while the first cost of a cooling tower with fan draught may be taken as approximately one shilling per pound of steam condensed per hour. As regards cost of upkeep, contrary to what one would expect, the wooden apparatus is found to be durable, the reasons assigned for this being free access of air to the material, and, when jet or ejector condensers are used, the deposit of oil on the surface.

The amount of water lost by evaporation is about 2 per cent. of the circulating water.

An incidental advantage of these cooling arrangements is that the water becomes deprived of most of its air, thus considerably lessening the work to be done by the air-pump.

CHAPTER XVII.

SWITCHING GEAR, INSTRUMENTS, AND ELECTRICAL CONNECTIONS.

THE term 'switching gear' covers the whole of the apparatus and devices for controlling and regulating the supply, as well as those for actually directing the current into certain mains, which is presumably its original significance, derived from the analogy of railway practice.

The switchboard is the most vital part of the whole system of supply, for to it converge all the internal work connected with the generating plant and all the external system of mains for feeding and distributing. It may be likened to the spinal cord, through which all the impulses travel, and which, if damaged, disables the entire organism. An electric supply system may survive the loss of a member, whether it be a generator or a main; but if its switchboard break down, it is at once *hors de combat.*

The primary object of a switchboard is to gather the current generated by the dynamo machines, and direct it, as desired, into the underground mains that convey it to the points of utilisation. Incidental to this object is the control of the energy, and the protection of the generators and mains from damage when abnormal conditions arise. The second main function of the switchboard is the control of the pressure of supply and the appliances for enabling machines to be suitably brought into service. Thirdly, the instruments necessary for the measurement of the output of the generating plant, the indication of the power supplied to the mains and its mode of distribution over the system, together with the measurement of the pressure at which it is supplied, form an integral part of the switchboard.

Switchboards fall broadly into two classes, viz.: (*a*) those intended for high pressures and moderately large currents; and (*b*) those for exceedingly large currents at low pressure. These two sets of conditions require very different treatment in some respects, but certain points in their design are common to both.

The essentials of all switchboards are:—

(1) The whole of the apparatus must be composed of incombustible materials.

(2) The disposition of the apparatus must be such that there shall be no danger to life, whether from shock, fire, or mechanical force, during its normal or abnormal working.

(3) Every part must be so calculated that it shall be free from heating when used continuously.

(4) The scheme of the board must be such that the purpose of every portion of it shall be self-evident, without reference to diagram or description; and, in some cases, it is desirable that the various parts shall be so locked mechanically or electrically that it is impossible for the various operations to be accidentally performed in the wrong order.

(5) All the working parts must be accessible for cleaning, and must be so arranged that they can be handled safely.

(6) Portions subject to wear must be easily renewable.

(7) In most cases, it is necessary that the board should be so arranged that it can be readily extended to deal with increased output without alteration or disfigurement.

The incombustibility of the switching gear is placed first, because it is, perhaps, the most important essential of all. There is a tendency to study appearance at the expense of this requirement, and to ornament the board with pitchpine or other wooden panelling; especially is this the case in Continental stations. Happily this practice is rapidly being abandoned in this country; but the boards that are coming in leave much to be desired, for to appearance is still assigned too much importance, handsome marble slabs being used to give a fine front, and, like whited sepulchres, to hide what is too often a chaotic mass of cables, insulated with such a highly inflammable material as indiarubber.

It ought to be recognised that, for a large central station, a switchboard is just as much a piece of mechanism as any other part of the plant, and should be treated as such. No one would think of boxing round a governor with polished pine, nor of lacquering the arms of a fly-wheel, and this class of work is just as much out of place on a switchboard. Its beauty should be that of design and fitness for the purpose it has to serve, not of adventitious ornament. On these principles, the present passion for marble panels is to be condemned; they are out of place in an engine room, they serve no purpose that could not be better fulfilled in other ways, they are expensive, and, finally, they soon become discoloured and cannot be readily cleaned. It is often contended that marble is better than slate; it certainly is in most respects, but slate is itself most unreliable, and its use should be avoided as far as possible.

A switchboard should consist as wholly of metal as possible. If for high pressure work, every particle of metal not forming part of the circuit should be connected efficiently to earth; and especially should all levers, and other parts that have to be handled, be most carefully kept at earth

potential. In high pressure work there is no half-way house between perfect insulation and earth, any partially insulated objects are liable to become charged to dangerous potentials, and especially is this the case with high pressure continuous current.

Although the switchboard framework and the platform carrying it should, for high pressure work, be carefully earthed, it is well for the attendants to be themselves insulated by means of rubber mats or rubber shoes, since, under no circumstances, should they form a conductor to earth. On the other hand, no reliance should ever be placed on this insulation by venturing to handle live objects. The Author has known insulated stools provided, and instruments carrying pressures of over 2000 volts handled; but such a practice is most reprehensible, so simple a matter as an uninsulated person handing a tool to one on a stool being sufficient to cause the death of both persons.

In the case of low pressure boards, an entirely different practice is desirable as regards earthing. Here everything that can be done to help the insulation should be resorted to, and, for low pressures, very moderate amounts of insulation are effectual, while dangerous charging cannot take place. There is not the necessity for keeping everything at maximum stress, and by resorting to double insulation the construction is greatly simplified and cheapened.

Switchboards ought to be so placed that access can be had all round them; the back should be as open as the front. They should be placed in such a position that they are unlikely to be affected in the event of a disaster at the station, and hence should be well away from all running machinery, and quite clear of steam or water pipes.

In large stations, it may be advisable to have separate boards for the generators and mains, the switches for connecting and disconnecting the generators being alone placed in the station, and the switches controlling the mains being grouped together in a distinct room. This is especially the case in a large high pressure station, the engine-room man having quite enough to do to look after synchronising and switching his machines in and out, without troubling about the feeders.

Switchboards in an engine room should be placed in such a position that they command a view of the generators; and with this end in view, they are usually mounted on an elevated platform. This should preferably be of steel, with steel floor-plates for high pressure work, or with a concrete floor, tiled, for low pressure boards.

In calculating the carrying capacity of the various parts of the switchboard that carry the current, it must be remembered that the temperature in an engine room is usually high, and the board must remain as cool as possible, otherwise switches may jam, or fuses may melt below their proper temperature.

In low pressure boards, some of the conductors have to carry very large currents, and care must be taken to make their shape suitable for radiating heat.

The chief danger of heating, however, arises from bad contacts, rather than from the resistance of the conductors. In order to avoid this source of trouble, not only must the design be such as to provide ample area of contact and sufficient pressure between the surfaces, but it must admit of the surfaces being easily and efficiently cleaned.

The importance of cleaning on high pressure boards demands more attention than has hitherto been bestowed upon it. It ought never to be necessary for a man to clean a piece of metal while it is alive; and when it is dead, it is a useful precaution to insist that it shall be temporarily earthed while it is being touched. This simple expedient would have saved more than one life had it been adopted.

The necessity for extension of boards from time to time, as the station grows, has led to the 'panel' system of construction, in which everything pertaining to one machine or one feeder is kept together on a single slab, all parts being similar, and new parts being added as required. The system is an excellent one, but, as usually applied, it leads to an immense amount of space being taken; and the compactness of the board, which is of great importance for its convenient and efficient working, is seriously interfered with.

The expense of some of these boards which have recently been introduced into this country, chiefly from America, is very high; in some cases, so high as to form a very appreciable proportion of the cost of the generating plant. In this country there are but very few manufacturers who have attacked the problem of central station switchboards in at all a serious manner; indeed, for high pressure switchgear, the work is practically in the hands of one firm whose product is most excellent, but here, again, the cost is exceedingly high.

There seems no good reason for this large cost, and it might be greatly reduced if more enterprise were displayed in the matter. At the present time, with the exceptions named, it appears to be thought sufficient to select a number of ordinary switches intended for all kinds of purposes, and to mount them on a large marble slab. What is required is the standardisation of the essential parts of the board in such a form that they will lend themselves readily to combination with one another in various ways. In this manner each board can be designed for the particular work it has to do, and, at the same time, stock parts can be utilised, while the completed work will present a proper unity of design. If the parts are designed with this end in view, the result can be attained; but this can never be done by assembling a number of incongruous units, each intended for its independent purpose, and in most cases provided with its own base and cover so that it can stand alone.

The organs of a switchboard are: (1) Switches; (2) Circuit breakers; (3) Directing apparatus; (4) Connections; (5) Support and Insulation of the apparatus. In addition to these are, of course, the instruments, synchronising gear, etc.

(1) The term 'Switch' is here restricted to the mechanism used for completing or interrupting a circuit at will. There are two distinct functions to be fulfilled, viz.: (*a*) the switch must carry the maximum current for an indefinite period, without unduly rising in temperature; and (*b*) it must break the circuit instantaneously and completely, without allowing an arc to bridge across the gap created by it, for an appreciable time.

The two requirements, though not incompatible, are difficult to combine, especially when large currents have to be carried, and hence it is not unusual to make a switch of two parts, either distinct or combined, so that one carries the current normally, while the other only carries it for an extremely short period of time immediately preceding the interruption of the circuit.

Every switch necessarily consists of at least two parts moving relatively to one another, and the carrying capacity will depend upon the cross-section of these parts, and on the form of the contact between them. The former is easy to arrange for, the latter calls for much care.

When two plane surfaces are placed in contact, it is a matter of extreme difficulty to secure that they shall touch all over and that the pressure shall be uniform. Even if this condition be attained by careful scraping, it cannot be maintained when the switch is in use, and, in consequence, the practice has arisen of subdividing one of the surfaces so that its various parts shall be independent of one another. Such surfaces either take the form of a strip of metal with saw cuts, as shown in fig. 39, or they are laminated, as shown in figs. 40, 41, 42, 43, and 44. The former class is well adapted for breaking the circuit, but is not suitable for very heavy currents, unless the current density be kept very low by having a large number of contacts. The laminated form is entirely unsuited to breaking the circuit while current is passing, but is admirable for carrying the heaviest currents.

Here it may be pointed out that in many cases, as, for instance, for switches used for switching generators in and out of circuit under ordinary circumstances, no appreciable current passes through the switch at the moment of making or breaking, the potential being maintained at the same value on both sides of the break. Occasionally, however, it may be necessary to break a large current, as, for instance, if an armature burn out. In such circumstances it may be worth while to have two switches in series: one for ordinary use, adapted to carry, but not break, the current; the other an emergency one, adapted to break the circuit with full current and normally short-circuited.

When a current is broken on interrupting a circuit, an arc is always drawn out between the contacts. This may cause destruction of the switch, or failure to interrupt the circuit, especially with high pressure, unless means be taken to extinguish the arc as soon as possible after formation. The difficulties on this score are enormously greater with continuous than with alternating currents.

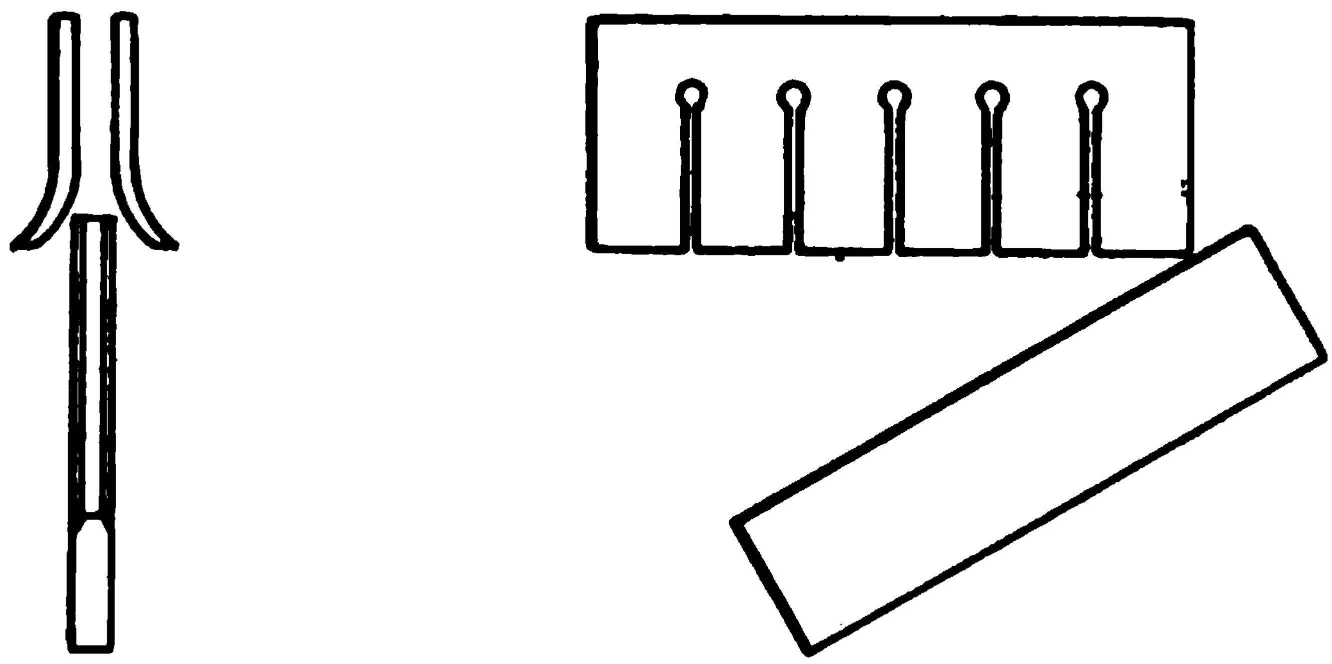


FIG. 39.—Knife contact.

Much ingenuity has been expended on the subject. Some of the most successful methods are the following, which are equally applicable to continuous or alternating currents, unless the contrary is stated:

The first and most obvious expedient is to provide a long break, as, the greater the distance, the more difficult it is for the arc to bridge across it. By itself, however, this long break is, in many cases, insufficient, since the presence of the vapour of the metal forming the contacts, together with the heating of the air, tend to greatly facilitate the passage of the discharge.

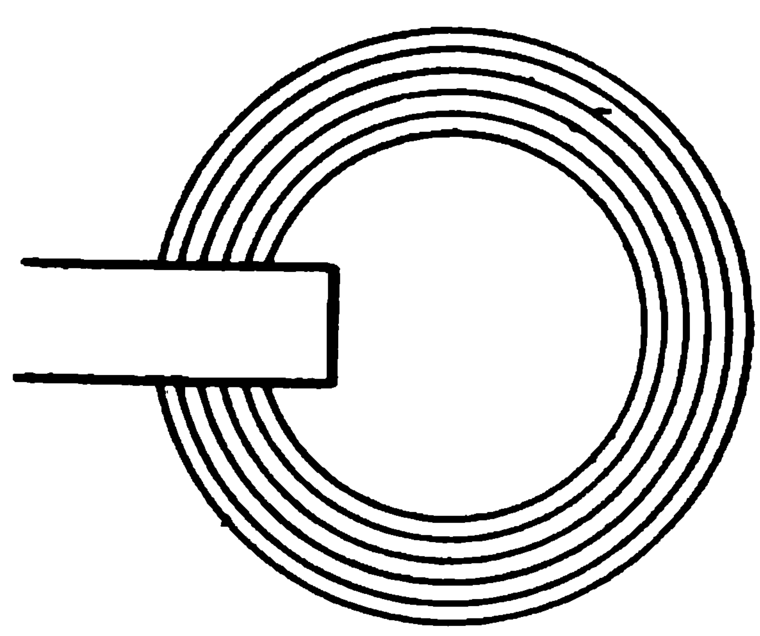


FIG. 40.—Ring contact.

If the break be effected very quickly, the arc has not time to vaporise so much metal, or to heat the air sufficiently to enable it to pass across the break; hence mechanical devices are usually introduced to cause the contacts to fly apart with great speed. No better example of such a switch can be given than the Thomson Houston switch, shown in fig. 45. In this, a flat blade passes in between a pair of flat surfaces, having saw cuts in them; the blade is divided into two portions, hinged to one another, and drawn together by a strong spring. On making contact, they act as one piece; but on breaking, the friction of the encircling tongues holds one of the pieces tight, the other leaving it behind and extending the spring. When a certain

tension is attained, the friction is overcome, and the piece flies off with great rapidity.

Another method of diminishing the amount of vapour formed consists in substituting two blocks of carbon for the metal. As carbon would not make sufficiently good contact for ordinary purposes, it is supplemented by metallic contacts which make contact after the carbon and break before it. In effect there are two switches: one the carbon one, making and breaking the circuit, but carrying little of the normal current; the other a metallic one, in parallel with it and conducting practically the whole of the current.

Fig. 41.

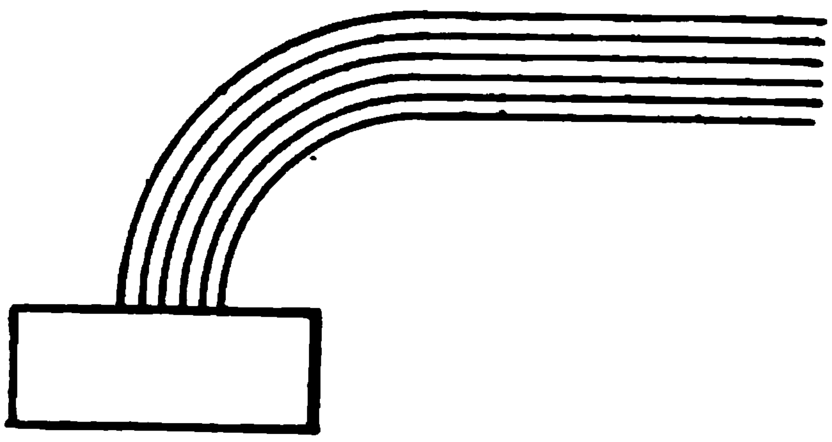


Fig. 42.

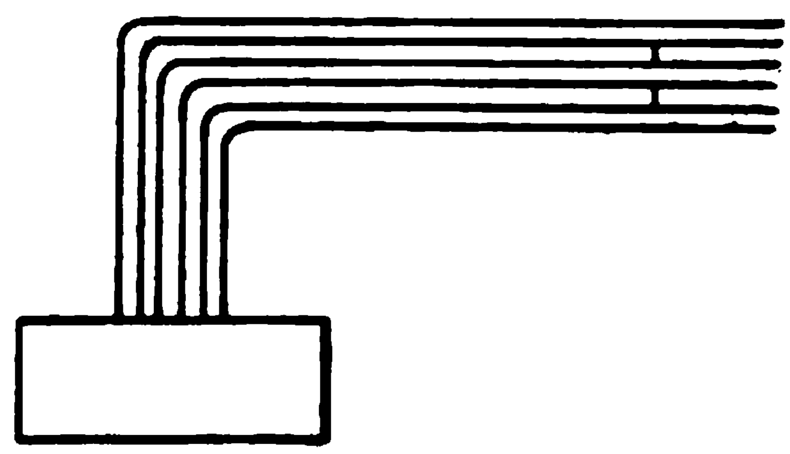


Fig. 43.

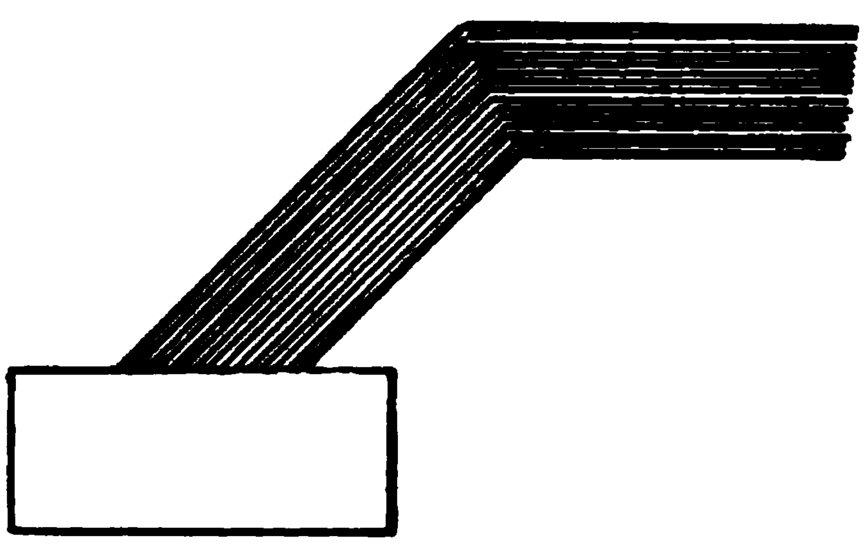
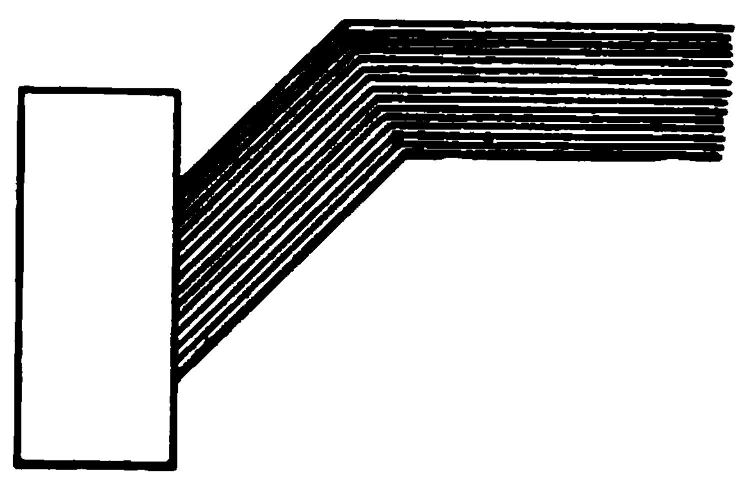


Fig. 44.



Figs. 41-44.—Laminated contacts.

Another device adopted is to destroy the arc mechanically. This is sometimes done by means of an air-blast directed on the contacts, sometimes by means of a shutter or flipper. An excellent example of the latter device is furnished by Verity's high pressure switch, shown in fig. 46. In this, two curved fingers pass through a block of marble into the contacts. As they are withdrawn, a shutter of refractory material, actuated by the handle, rises between the contacts and the fingers, and shuts off the holes in the marble, thus, as it were, shearing off the arcs.

A remarkably effective manner of blowing out the arc is one applicable only to switches for continuous current. This consists in causing the break to be made in a powerful magnetic field set up by the current broken. In some cases an iron core is used, in others there is only a solenoid. This method is most effectual, the arc being blown out instantaneously with a report like that of a gun.

A number of breaks in series tends greatly to get over the difficulty of arcing, it being much more difficult for the discharge to be kept up over a series of gaps than across a single one of a length equal to the sum of their lengths.

In breaking large currents at high pressures, recourse is sometimes had to bridging the main circuit by a resistance, and after the current is thus reduced, breaking it in one of the ways described. The final break is sometimes made by means of a series of cylinders fixed very close to one another, and formed of an alloy of zinc and antimony. This alloy gives off a vapour that is non-conducting, and stifles the arc if the cylinders be not too far apart.

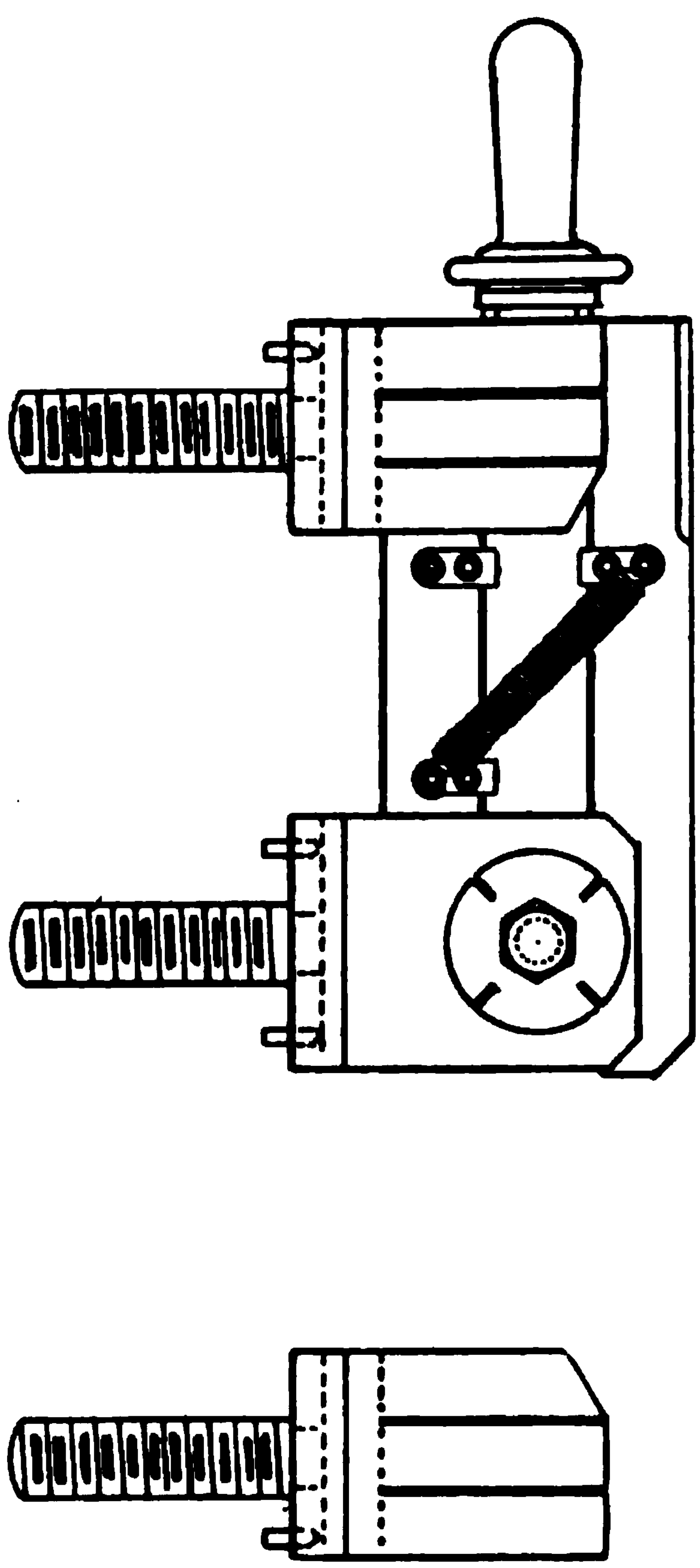


FIG. 45.—Thomson-Houston switch.

It will be seen from the foregoing that for currents of moderate pressures, up to, say, 500 volts, there are many ways of making satisfactory switches; while for fairly high pressures of, say, 2000 volts, whether continuous or alternating, there is no great difficulty in dealing with the problem. For high pressures, however, of 5000 volts and upwards, for example, the question of switching is a most serious one, and merits a great deal of attention. Switches are required to deal with large amounts of power, say 5000 H.P., at pressures varying from 5000 to certainly 10,000 and possibly 20,000 volts; and although, naturally, every effort will be made in practical operation to avoid opening such switches with a large load on, yet cases may arise in which it may be imperative to do so.

The tendency at present is to resort to exceedingly long breaks, and this practice is undoubtedly right; complete satisfaction will probably be attained by combining with this several breaks in series, supplemented, probably, by an air-blast on the contacts, or by a supplementary shunt break on a non-arcing metal.

In all cases, switches should be provided with handles of sufficient length to enable the attendant to stand clear of the switch when operating it.

The utmost care should be exercised to prevent the possibility of a main

that is under repair being accidentally switched on. Many devices will suggest themselves. One used a good many years ago by Mr Ferranti consists in having a staff for each main, having its distinguishing number or name painted on it; this staff is normally hung up near the switch controlling the main. As long as the switchman has the staff he may make the main alive; but if work has to be done, the foreman of the men working on the main sees the main switched off, and takes the staff, retaining it until his work is completed. The switchman must not put the main on until he again has the staff. This obviously depends on moral effect for the degree of safety afforded; a development of the same idea, whereby the main is physically blocked, consists in locking up the switch by means of a padlock, the key of which is retained by the mains foreman.

As regards the interlocking of switches, already referred to, it is not necessary to enter into details, as the cases in which it is required are usually special ones. An example of one designed by the Author to meet the case of a motor generator separately excited may be instanced. Here the object was to secure that the magnet switch should be put on before the starting switch, and not taken off until the starting switch was off. The lock consisted of a disc carried by the starting switch, having a hole drilled at one point. Into this hole fitted a steel pin, worked by a link from the magnet switch. When the magnet switch was off, the pin engaged with the hole, and prevented the starting switch from being moved; as soon as the pin was withdrawn by the magnet switch being put on, the starting switch could be operated, and the magnet switch could not be taken off until the hole in the disc was brought again opposite the pin by moving the starting switch into the off position.

FIG. 46.

(2) Next in importance to switches, and closely connected with them, are Circuit breakers. These, in effect, fulfil the same functions as a switch, but are rarely used to make contact, only to break it, and this they do automatically.

The most widely used circuit breaker is known as a fuse, and consists of a piece of metal, so proportioned and constituted that, when a certain predetermined current passes through it, its temperature rises sufficiently to produce fusion of the material and consequent interruption of the circuit.

Fuses are open to many objections. Perhaps the chief is their uncertainty, for, although under absolutely identical conditions, a fuse will always melt with the same current, these conditions are often impossible to accurately reproduce in practice.

The precise current at which a fuse will go depends, among other things, on (1) the temperature of the surrounding air; (2) the mass of the contacts to which it is clamped; (3) the condition of its surface as to heat emissivity; (4) the facilities for radiation, as affected by surrounding objects; (5) the cooling by convection; (6) the length of time it has been in use, this affecting the amount of oxidation of its surface and the brittleness of the metal; (7) the suddenness with which the current is applied, a given fuse being able to carry many times its ordinary fusing current for a very short time.

Other objections to fuses are that they are expensive and take an appreciable time to renew after they have acted, besides giving rise to a certain amount of dirt from the vaporised metal.

Many different metals may be employed for the purpose.

For moderate currents, at low pressures, pure tin is probably the best, as it melts at a low temperature. It has the drawbacks that it spatters about greatly, and the fumes are heavy, abundant, and objectionable.

For high pressure work, and for large currents at low pressure, copper is satisfactory, as it gives very little vapour, and does not spatter, but it becomes red-hot some time before it melts, being liable therefore to cause dangerous heating, and when it fuses, it breaks up into incandescent globules which scatter about and retain their heat for a considerable time, thus introducing danger of ignition, if inflammable substances be near.

Aluminium is stated to be very satisfactory for high pressures and to possess non-arcing properties.

For large currents at low pressure, flat strips of metal are usually employed when fuses are used at all, but for ordinary supply work at low pressure, it is usual to dispense with fuses altogether, as introducing more trouble and danger than they save.

In the case of high pressures, in which the current is usually moderate, thin round wires are generally used, a number of separate strands in parallel being employed for larger currents in preference to thicker wires, such an arrangement being simpler and more likely to fuse quickly. The fusing current of several strands will be substantially less than the sum of the fusing currents of the individual strands, because the cooling effect is much less when they are laid up together.

Thick wires of tin sometimes fuse in a very remarkable manner. The interior becomes liquid, while the exterior remains solid, confining the molten metal like a tube. This is undesirable, and is a drawback to their use.

Fuses usually have to be replaced promptly, and, to facilitate this, the wire is mounted in such a manner as to be rigidly held in suitable terminals which only require clamping, or, in some cases, merely pushing into the terminals on the switchboard.

When a circuit is controlled by a fuse, it should always have a switch in series with it, so that the fuse may be put in with no current passing. If this be not done, there is great danger of a serious accident arising through its blowing in the attendant's face when he replaces it. Some fuses are so mounted that they serve the double purpose of switch and fuse; but, for the reasons stated, most of them are dangerous.

Since fuses, like switches, open the circuit, there is the same difficulty to contend with in the formation of an arc; but, inasmuch as they always operate at maximum, or rather at excess current, it is present in all cases and in an aggravated form. The liability to arcing is still further increased by the presence of the vapour of the melted fuse wire.

Some of the devices for stopping arcing at switch contacts are adapted to fuses, while some of the expedients are peculiar to them. Invention has been chiefly applied to designing fuses for high pressure circuits, since, as already stated, these appliances are usually dispensed with in low pressure stations; or, when the circuits are automatically interrupted, a different kind of circuit-breaker, described below, is resorted to.

One of the most successful methods of extinguishing the arc consists in plunging the terminals beneath the surface of an insulating oil. This is the principle of the Ferranti high pressure fuse, which is very largely used in this country. This is shown in fig. 47.

A rectangular vessel of porcelain is divided into two portions, each of which contains a metal tongue, hinged at one end at the bottom, and depressed by a spring. Each tongue communicates with an external terminal.

The fuse wire is fixed to the two free ends of the tongues, which are drawn up for the purpose, and rests on the top of the partition dividing the compartments. The fuse thus holds up the ends of the tongues against the tension of the springs. When the wire melts, the tongues disappear beneath the oil, and the porcelain division is interposed between them. The result is that the arc is instantaneously extinguished. The porcelain vessel has a handle at the end, opposite to the contacts, and this serves to push it into position between the circuit terminals. The only drawback to this fuse is the danger of ignition of the oil, which, however, does not often occur.

Another successful method of stifling an arc from a fuse is by surrounding the wire with a non-conducting dust, as is done in the Mordey fuse.

In this the wire is enclosed in a glass tube, and passes through an incombustible dust within the tube, a clear space being left at the middle point.

A third device is to place the wire in a tube open at both ends, as in the Bates fuse, shown in fig. 48. The sudden evolution of heat causes the air within the tube to expand suddenly, and to rush out at the ends of the tube, blowing out the arc as it does so.

FIG. 47.—Ferranti oil break fuse.

One method of extinguishing an arc should be referred to here. It consists in allowing it to take place between the bases of two horns which gradually curve backwards as they rise. The arc, which tends always to rise, travels up these until the distance between the horns becomes too great for it to continue.

The magnetic blow-out principle is applied in the Thomson-Houston fuse

for continuous current circuits carrying currents of moderate amount and pressure, and is very effectual. The fuse is placed in a very intense magnetic field, and is blown out with great violence.

The disadvantages of fuses have already been pointed out, and they have led to the introduction of an entirely different class of circuit breaker. These are, in effect, switches, arranged so that they tend to fly off when a retaining mechanism is tripped by the current attaining a certain value. The means taken to suppress the arc are similar to those for ordinary switches.

The Thomson-Houston circuit breaker for continuous currents of moderate pressure is shown in fig. 49. Here the current is carried by a laminated switch of ordinary design, incapable of breaking the current, and by another small switch in parallel with it, which breaks after the principal switch, the break taking place in a powerful magnetic field set up by the current broken. The switches are put on by hand against the pressure of a powerful spring, and are held on by a catch which is released by the same magnet that blows out the arc.

The Westinghouse circuit breaker depends on carbon contacts and rapid motion for extinguishing the arc.

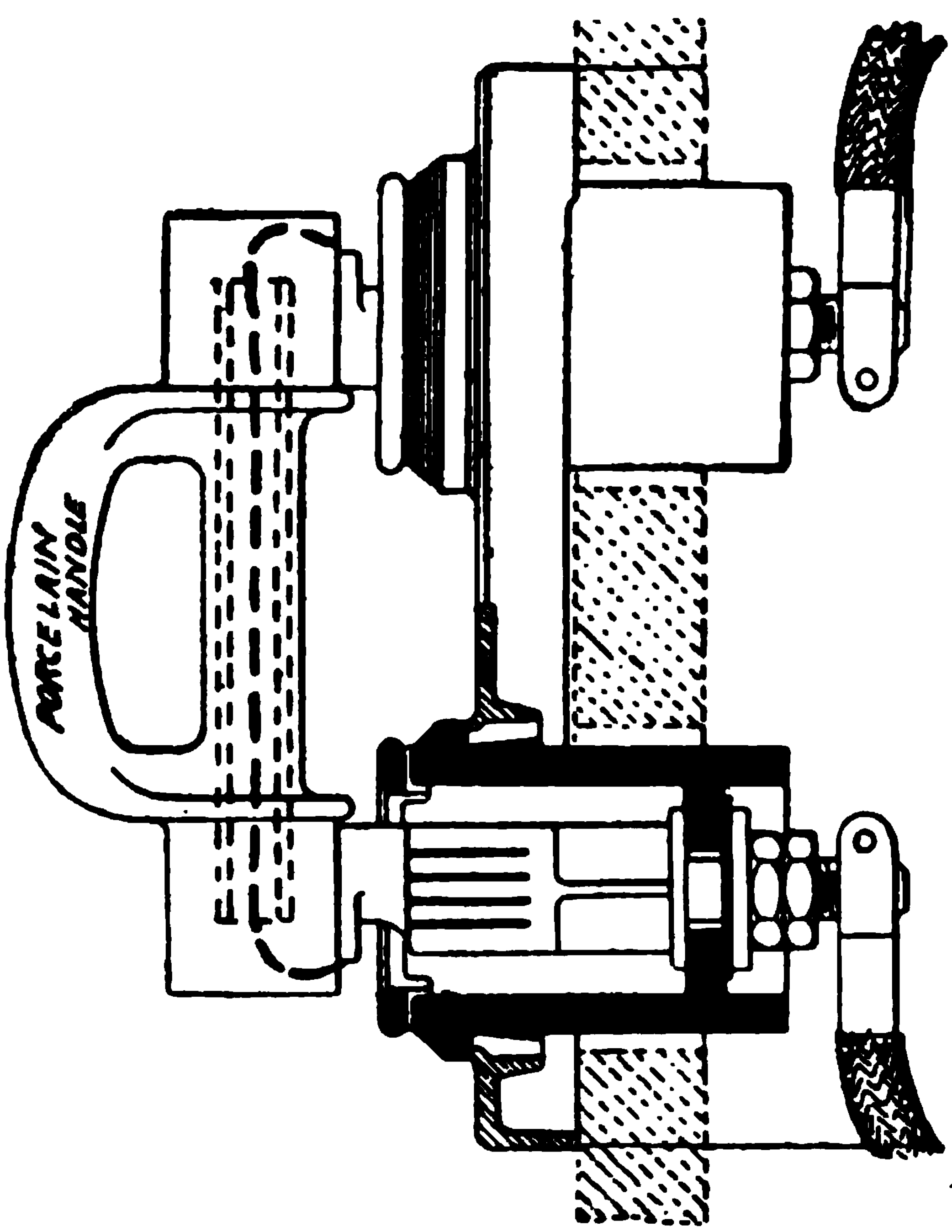


FIG. 48.—Bates fuse.

The Cutler-Hammer is remarkable for the excessive speed of the break, this being relied upon, in conjunction with carbon contacts, for stopping arcing. The rapidity of motion is attained by means of a pin, pressed forward with great force directly at right angles to the moving part.

The Sentinel circuit breaker operates by a very brittle bar of metal being smashed by a spring; the metal breaks at the ordinary temperature, and thus gives rise to but little vapour.

Mechanical circuit breakers of the types described are chiefly applicable

to low pressure circuits, fuses being still chiefly used for high pressure work. They possess the advantage that they can be very quickly reset, and there is no expense for renewal of material. Like fuses, they should be controlled by ordinary switches in series with them.

Automatic cutouts are sometimes arranged to open the circuit when the current passes through zero, or attains a given magnitude of opposite sign.

The Nevill cutout, shown in fig. 50, is an example of this type. It is usually applied to batteries. It consists of a metallic bridge held in position, with its ends dipping into two mercury cups, by the current, and, when this passes through zero, the lever carrying the contact bridge, being overweighted at the other end, withdraws it.

FIG. 49.

The cutout shown in fig. 51, made by the Electric Construction Co., is

FIG. 50.

arranged to operate with a reversed current, and is used on high pressure continuous-current circuits of 1000 and 2000 volts.

A similar device for alternating currents presents considerable difficulties, which have, however, been successfully overcome in the Andrews 'discriminating' cutout, described in Chapter XXII.

Fig. 51.

The general design of the switchboard, especially for high pressure work, should be such that, if an arc take place, there is nothing above it to which

it can climb, nor in its immediate proximity to which it may be diverted. Switches, for this reason, should always have their contacts between which the arc takes place fixed at the top, and high pressure switches should be divided from one another by partitions of refractory non-conducting material.

(3) So far the switches that have been considered have been merely for opening and closing the circuit; a switchboard frequently, however, has to perform the function of directing the current from a particular machine to a particular circuit.

Thus, in alternating current stations, in which the generators are not run in parallel, each machine has its own circuit or group of circuits. A not uncommon device in this case is to use highly insulated flexible conductors terminating in plugs, one of which is inserted in a suitable terminal on the circuit and the other in a similar one on the machine.

For low pressure work, probably the most satisfactory system is the so-called 'gridiron.' This consists of a series of bars, one set horizontal, the other vertical, the two sets being in different vertical planes, separated from one another by insulators. At each point of crossing, holes are drilled in both bars, the one in the hinder one being tapped, and that in the front one plain, but slightly larger in diameter. A plug, screwed at one end, and having a flat collar at the other, is inserted at the desired point, and screwed into the back bar until the collar bears tightly on the front one. In this way, any horizontal bar to which the machines, say, are attached, can be connected to any vertical one, communicating with the circuits.

One case in which distributing devices are required has already been mentioned; others arise when different circuits require to be run at different pressures, or when a machine is used sometimes for lighting and sometimes for traction work. As a general rule, they should not be operated with the current on.

(4) The next important matter is the connection between the different items of a switchboard. It is usual for a number of generators to deliver into a common conductor known as an 'omnibus,' or, more shortly, 'bus' bar, and from this a number of circuits are fed. In stations supplying a large district there will probably be several omnibus bars run at different pressures. The great point to be borne in mind is to so arrange the design that objects requiring to be connected shall be in close proximity to one another, and be capable of being joined by straight bars. Cables covered with insulating material should never be used for the purpose; and the cables from the mains and from the machines should, if low pressure, be quite away from the board itself, and connection be made with them by bare rods. In high pressure work the cables should be as remote as possible from the working parts and should be lead covered and buried as far as practicable.

All cables, where they join on to the bars leading to the switchboard and the board itself, should be sweated into suitable eyes, which are then clamped

on to the desired part. One of the best forms of clamp is a circular plate, clamped by means of three set screws. In some cases, a single plug having a collar like the one described in connection with the gridiron switch, and passing through a plate having a circular hole in it attached to the cable, is very convenient (*see* fig. 52). Here the contact derived from the collar of the plug is supplemented by the flat surfaces in contact. A plain lug, clamped under a nut, is excellent for moderate currents. Cone connections, shown in fig. 53, have a certain amount of popularity, but are dependent for

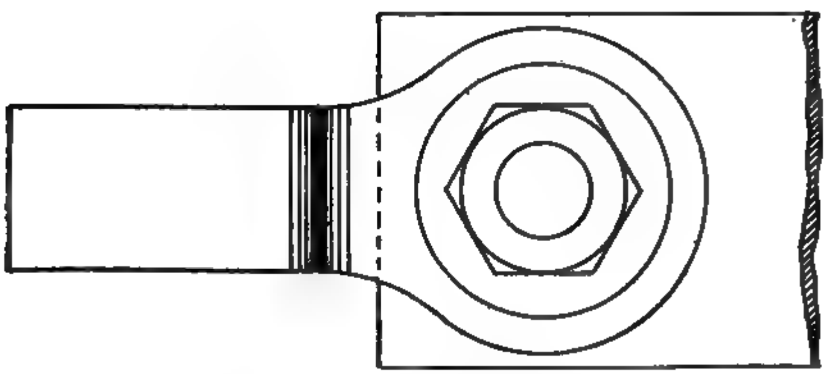


Fig. 52.—Plug and plate connection.

their efficiency on very accurate and true work on the surfaces, or they may bear only on a few lines, while they are sometimes difficult to undo.

Copper should be used wherever possible; if it cannot be used, gun-metal may be substituted. Aluminium promises to be useful in certain cases. In place of being cast, 'extruded' metal is very suitable, on account of its density and homogeneity; it can, however, only be used for certain sections.

(5) The main support and framework should certainly be of cast iron or wrought iron riveted together.

The most desirable insulating material is porcelain, which is satisfactory for all pressures. It will stand almost any amount of compressive strain, if its surface be ground flat, or if soft buffers be placed next it. Slate and

marble cannot be considered insulators, except for low pressures, and even then they are most treacherous. Mica is very useful under certain circumstances, while ebonite is admirable for brushes and washers and for situations in which it is not exposed to the air or light. Sulphur cement enables very neat and strong work to be carried out, but is open to the objection that it softens with heat and may take fire.

The regulating switches for varying the number of cells from a battery, and for altering the resistance in the field circuits of generators and boosters, are usually accommodated on the board. These should all be of substantial and solid design; and, if fixed on slate bases, as they frequently are, should

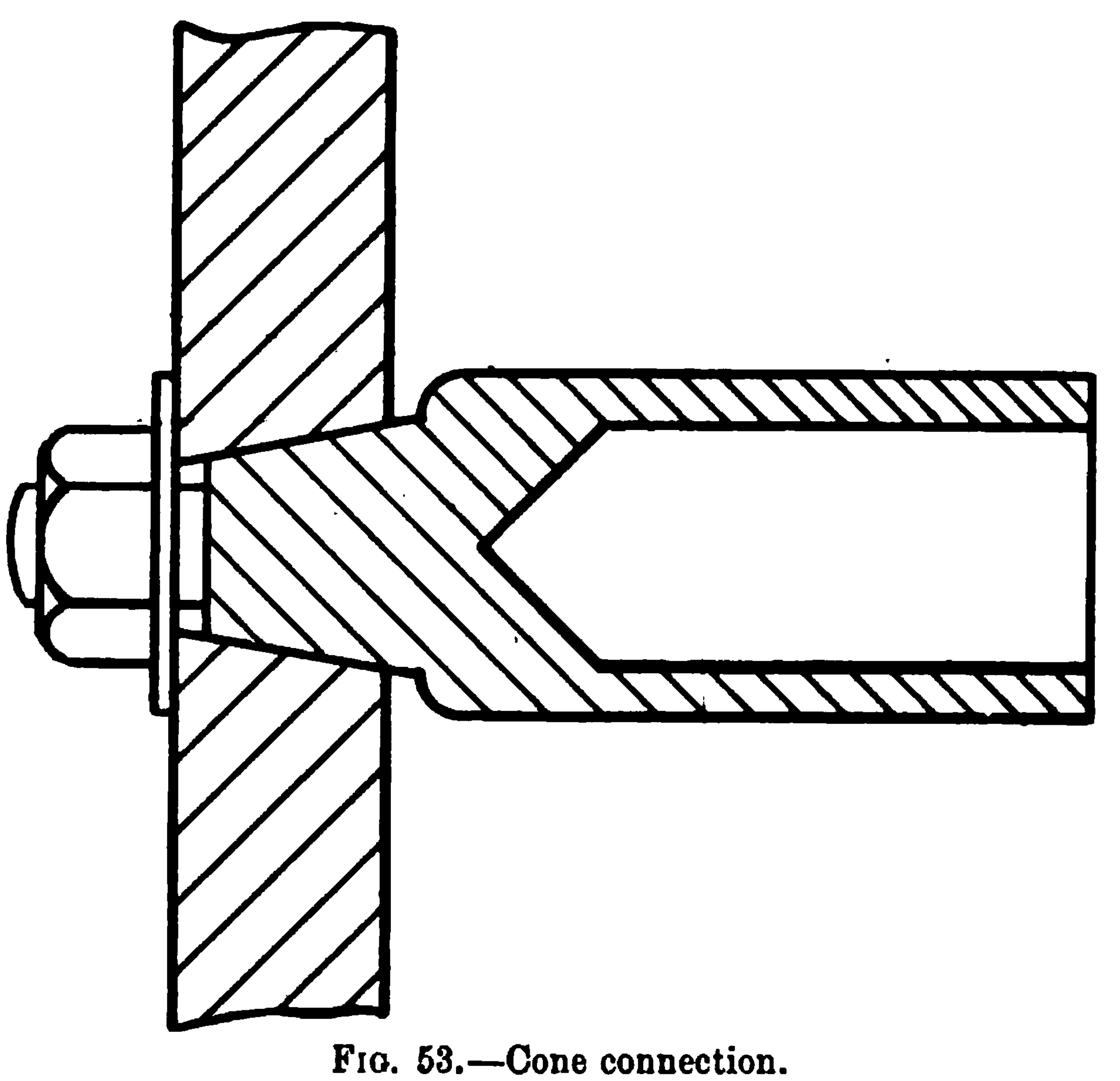


FIG. 53.—Cone connection.

be insulated, as a whole, by means of ebonite-bushed screws. The circuit is rarely, if ever, interrupted on them, so no trouble from arcing arises. Resistances should be enclosed in ventilated cases, and should be entirely insulated with porcelain if of open coils. They should be of a material that will not deteriorate or become brittle under the influence of the air, as many alloys do. Resistances submerged in oil, and completely enclosed, are very useful, while another excellent form consists of flat strips wound with mica or asbestos soaked in a bituminous compound between successive layers. The resistances should be fixed as close as possible to the switches, so as to diminish the length of connecting wire, which should be bare, if possible. Where this is difficult, it may be well to put the switch away from the board with the resistance, and connect it mechanically to a wheel or bar on the board itself.

The instruments usually required on a switchboard are: (1) Watt-hour meters, (2) Ammeters, (3) Voltmeters, (4) Recording Ammeters and Voltmeters.

(1) The Watt-hour meters should be placed on the machine circuit, not on the feeders; they will thus operate chiefly on full load and near about the same rate, and errors due to their indications following an erratic law will thus be practically eliminated. The most suitable are the Aron and the Thomson, described in Chapter XXV. The latter is influenced by strong fields, while it is not desirable to place the former in them. Conductors in the neighbourhood of the meters should be concentric.

(2) Ammeters may either be connected directly in the circuit, or may be connected as a shunt to a low resistance of known value, through which the current to be measured passes. The advantage of this latter course is that the instruments can be grouped together in any convenient position, irrespective of where the conductors are. The disadvantage is that temperature errors cannot be fully allowed for. There are two sources of error due to temperature, viz.: (1) changes in temperature of the coil of the instrument, due to changes in that of the surrounding air; and (2) changes in the resistance of the conductor, across the terminals of which the instrument is connected, due to the heating caused by the current to be measured.

It is possible to eliminate the first error and leave the second uncompensated for, or else to get rid of the second by employing a metal having a negligible temperature coefficient and neglect the first error A compromise has to be effected by partially correcting for both.

The so-called 'edgewise' form, in which the index is bent round at a right angle and moves over part of the surface of a narrow cylinder, the axis of which is the centre of motion, is most convenient, and enables a large number of ammeters with very open scales to be got into an exceedingly small space, while they can be more easily read than the dial form. A set of twelve such instruments is shown in fig. 54.

The essentials for a switchboard ammeter are: fair, though not necessarily minute, accuracy; dead-beatness; strong construction, especially as regards the pivots; an open, coarsely graduated, conspicuous, direct-reading scale; capacity for heavy overloads of short duration; freedom from heating.

(3) Voltmeters for high pressures are almost necessarily of the electrostatic type, while for low pressures the instruments are very reliable, but suffer from contracted scales. Both the magnetic and moving coil types are available. The most desirable is the moving coil.

The essentials for switchboard voltmeters are: extreme and constant accuracy over a short range, say, for 10 per cent. on either side of the mean standard pressure; dead-beatness; strong construction; bold pointer, and clearly visible, large graduations; freedom from heating during continuous

working. The 'illuminated dial' form, in which the pointer moves over a translucent scale lighted from behind, is admirable. Such an instrument is shown in fig. 55.

Fig. 54.—Set of edgewise ammeters.

(4) Recording instruments are those which show, by means of a line traced on a graduated sheet of paper kept travelling beneath a pen, the mode of variation of current or pressure. All are open to the objection that the friction between the paper and the pen interferes with the movement of the pen and with the rate of the clock, while the inertia of the moving parts tends to wipe out small variations and exaggerate large ones.

One of the most satisfactory recording ammeters is that made by Messrs Elliot Bros., in which a continuous strip of paper is unreeled beneath the pen; while one of the best recording voltmeters is the Kelvin, in which the pen has a point resembling that of a stylographic pen.

As an example of a switchboard, designed by the Author, embodying the principles ennunciated in this chapter, may be given that shown in fig. 56.

This is of the gridiron type, with bare copper rod connections; it is constructed wholly of incombustible materials—metal and porcelain—with the exception of ebonite bushes and washers to insulate the bolts. The positive

FIG. 55.—Illuminated dial voltmeter.

and negative conductors, differing in potential by 400 volts, are on two separate boards and some 8000 H.P. is controlled; the instruments used are of the edgewise type.

FIG. 66.—Switchboards controlling 8000 H.P., embodying principles [illegible]

CHAPTER XVIII.

DISTRIBUTING MAINS—DRAWING-IN SYSTEMS.

THIS subject is one that demands the closest attention, for the proportion of the total capital invested in the undertaking represented by the mains may amount to as much as fifty per cent.: and, so far as the success of the supply is concerned, far more depends on the mains than on any other part of the plant, for, unlike the generating plant, mains cannot practicably be duplicated, and, once laid, they are out of sight, inaccessible, and exposed to many deleterious, and often unknown, influences.

Mains fall broadly into three classes, viz., (1) Distributing mains, (2) Services, and (3) Feeders.

Distributing mains form a kind of buffer, or a common meeting ground, between the services on the one hand and the feeders on the other. Their office is to take the supply brought by the feeders from the generating station, to distribute it over a given area, and serve it out again at the required points to the service mains which deliver the energy to the individual consumers.

Services are the conductors through which current is supplied to any particular consumer to whose sole use they are allocated.

Feeders are mains connecting the generating station directly to a definite point on a distributing main, and to which no connection is made for any purpose at any other point.

Distributing Mains.—The conditions to be fulfilled are as follows:—In the first place, it is important that the mains should be so arranged that they can be tapped at any point along their length. They should not require that connecting boxes be laid down at predetermined points, for many of these will certainly be wasted, and many will be found to be in inconvenient positions, necessitating either the entrance of the service line at an unsuitable point in the building, or the running of unnecessarily long connections. Jointing on of service lines should be easy, quickly effected, and should not require highly trained men or special contrivances. While low first cost is highly desirable, it is of greater importance that the mains should be of durable materials, and should be unlikely to fail; for a failure of

a distributing main is of much greater importance than the failure of a feeder, since it is easy, and comparatively not costly, to provide reserve feeders, while it is out of the question to duplicate distributing mains. Further than this, feeders can be readily withdrawn, while a distributor cannot be renewed without serious interruption of the supply and excessive labour for rejointing. The insulation of conductors should be permanent and steady; it need not be extremely high. The system of distributors should be as flexible as possible, since it is always preferable to lay them under the footways and near the buildings, and many obstacles to a straight course are in consequence met with. The mains should afford security against fire, explosion, or other damage to person or property, and they should interfere as little as possible with the surface of the street or pathway. They should be unaffected by the soil, as well as by rats or other vermin.

Mains fall broadly into two systems—drawing-in and built-in.

Drawing-in Systems.—The drawing-in system is very attractive in theory; and in practice has, as we shall see, under certain circumstances, marked

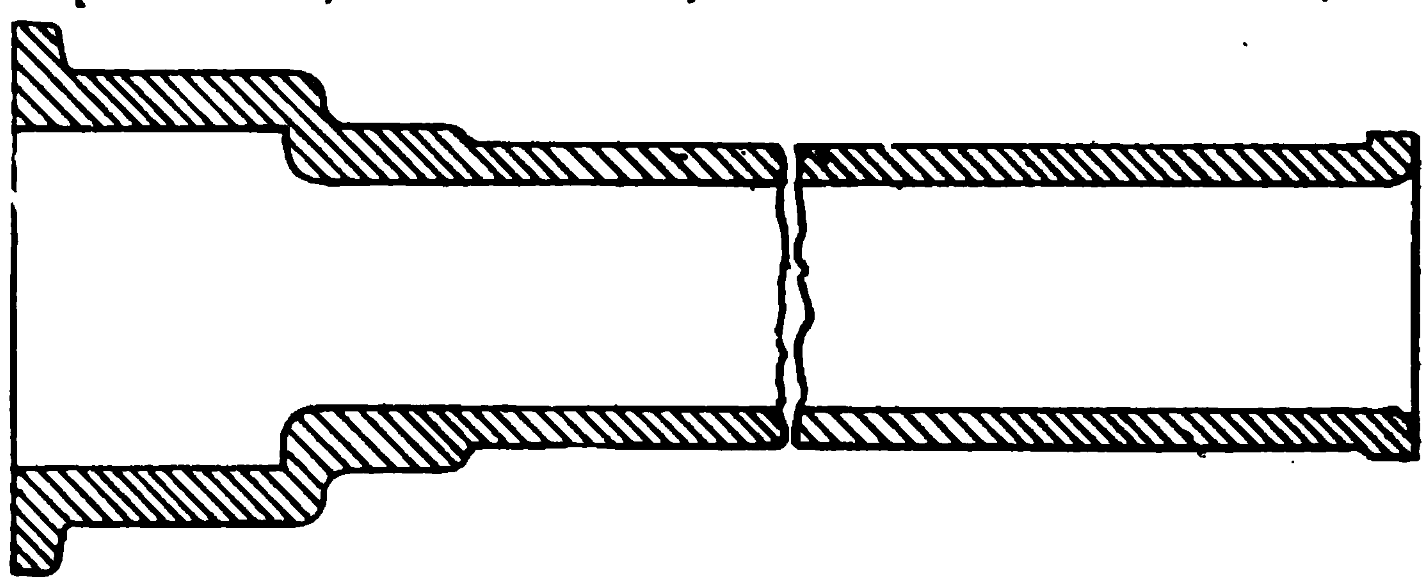


FIG. 57.—Spigot and socket pipe with rounded edges.

advantages for feeders, but for distributors the title is a misnomer, for every drawing-in system becomes a built-in system as soon as T-joints are made to connect consumers to the conductors. It is impossible to draw the conductors out without cutting all the branch wires; and to draw in additional cables on the top of old ones is to court certain disaster, for they will assuredly damage both the branch connections and the main conductors.

The earliest form of conduit used was cast iron pipes, similar in all respects to gas pipes, except that the edges were carefully rounded, and in many cases a steel faced disc rimer was passed through the pipe to dress off any irregularities there might be.

The pipes are usually spigot and socket, in preference to turned and bored, and are jointed either with cement or lead. Fig. 57 shows a section through a spigot and socket, and exhibits clearly the rounding of the edges. The pipes are usually nine feet long. They are generally coated inside and out with Dr Angus Smith's preservative composition.

The objections to cast iron pipes are: cost, liability to rough places, causing damage to the insulating covering of the cables when they are drawn in, and the fact that if the insulation break down, a dead earth is almost certain to result.

It is preferable to have a separate pipe for each cable, but the expense thus entailed is usually prohibitive. Attempts have been made to employ a pipe with cast iron partitions, but the difficulties of jointing the several lengths together are considerable, and the pipes are costly; for these reasons they have not come into extended use.

Glazed earthenware pipes, similar to those used for sanitary purposes, have been largely used, the joints being made with cement. This is open to the serious objection that there is danger of cement getting into the interior of the pipe, and cement is fatal to many kinds of cable. Moreover, there is danger of the pipes not being concentric at the joints, and of sharp edges being left. The workmen employed should be closely watched, otherwise the cement may only be placed at the top where it shows, while underneath there is none, and the joint lets in water. The pipes are usually in 2 foot lengths, but they can be got 2 feet 6 inches long, and this is a better length for the purpose. On account of the larger number of joints, earthenware pipes take longer to lay than cast iron.

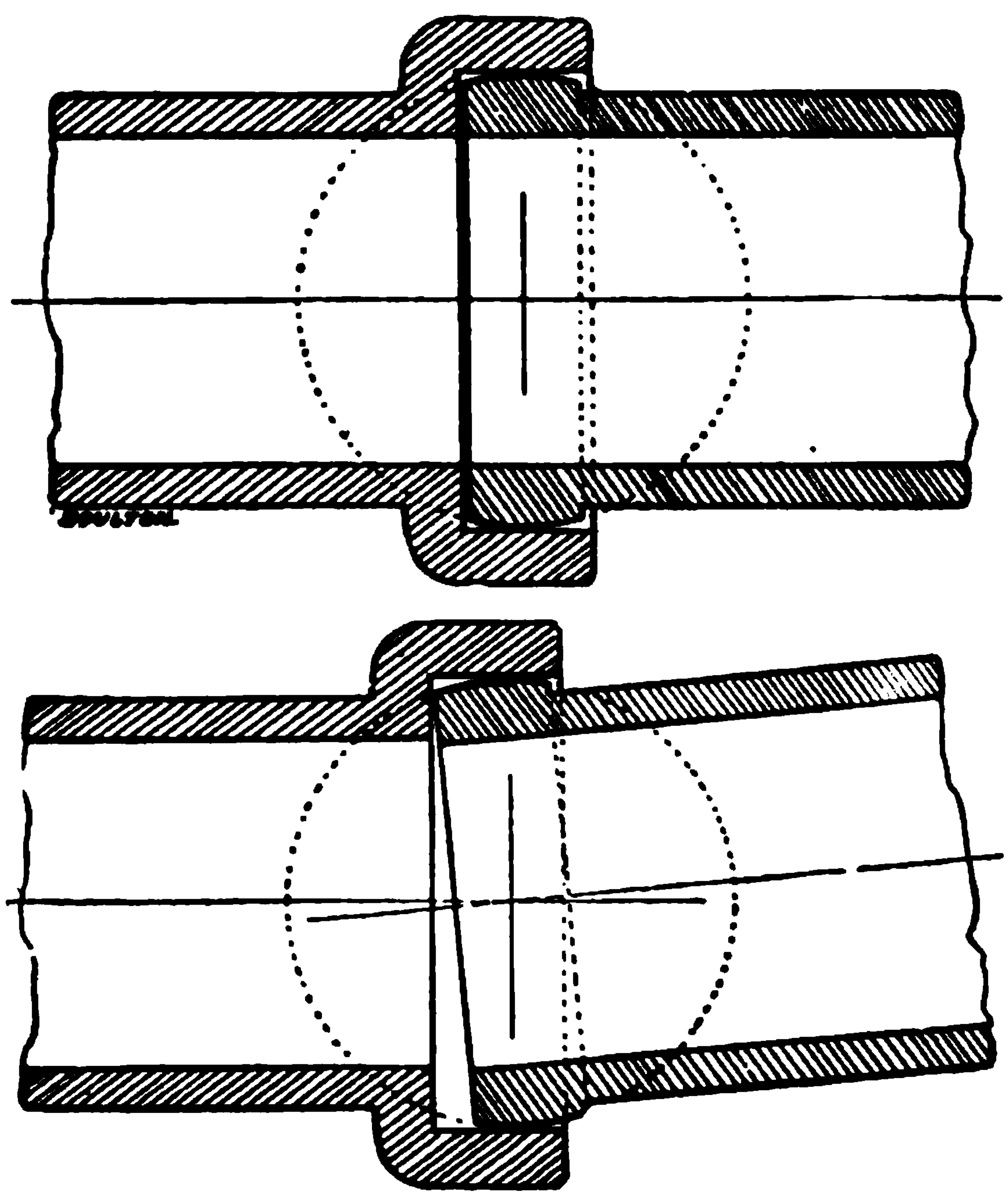


FIG. 58.—Ball and socket joint.

A great improvement on the common sanitary pipe is that furnished with Doulton's patent ball and socket joint, shown in fig. 58. Here there is fixed on to the ends of the pipes a material composed of sulphur, sand, etc., accurately moulded, so that the spigot end forms part of a true sphere, while the socket end is part of a cylinder. The sphere will just not fit into the cylinder unless it be greased, when it slides in and makes a perfectly water-tight joint.

The advantages are, primarily, that moderate sinking of the ground will not cause the joints to open, the ball and socket arrangement allowing considerable movement, without impairing the watertight fit; there is no danger of a joint not being concentric; and the pipes are very rapidly laid. Incidentally, there is the further advantage that the pipes are of exceedingly good quality, as the makers

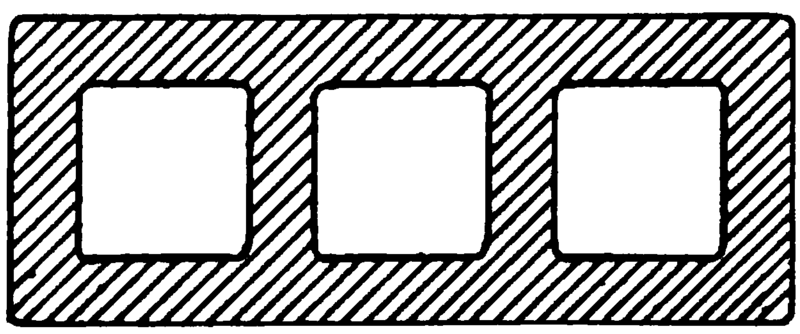


FIG. 59.—Stoneware casing.

only put this class of joint on pipes that have been tested for soundness under hydraulic pressure. When laying these pipes, great care should be taken not to handle them roughly or chip the joint. The straw surrounding the joints should not be removed till just before actually laying the pipes.

Just as a cast iron pipe with several ducts has been employed, so, in the case of earthenware, Messrs Doulton have brought out a stoneware casing, with a separate way for each cable. This is usually rectangular in section, the ducts being square. A casing with three ducts is shown in fig. 59.

The casings are made in 2 feet and 3 feet lengths, and several methods of jointing them together are employed. The earliest, and perhaps the best, consists in passing through the ducts steel mandrels, having one end surrounded by a rubber cushion; these cushions are forced against the sides of the ducts by being compressed lengthways by means of a screw worked from the other end, thus preventing the jointing material running in and so blocking the duct, or forming an irregularity on its interior surface. The arrangement is shown in fig. 60. A cast iron plate is placed under the joint, and a cast iron mould is placed over the top and sides. Into this, composition, similar to that used on the patent jointed pipes, is poured, and

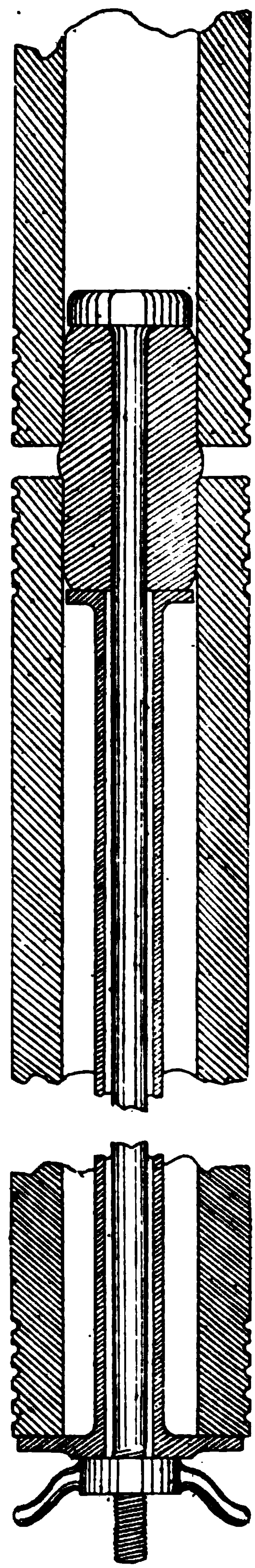


FIG. 60.—Method of jointing together lengths of stoneware casing.

sets rapidly; the mould is removed as soon as the joint is cool, the cast iron plate being left in position. The mandrels are then withdrawn.

It is obvious that the casing takes much longer to lay than pipes, and it is a good deal more expensive; moreover, the amount of space required is considerable, and it cannot so readily be taken round obstructions.

It has been alleged that the glaze on the interior of stoneware pipes is detrimental to certain classes of cable, mainly because sodium has been observed in the salts found encrusting faulty cables. As common salt is used in connection with the glazing process, it seemed a natural inference that the one was derived from the other, but investigation has shown that the amount of sodium present in the glaze is far too small to account for the quantity found. It is far more probable, if not actually certain, that the sodium is derived from substances mixed with the insulating material of the cables itself.

Another form of many-way conduit which has been considerably used is the Callender-Webber. This is moulded from a mixture of gravel, sawdust, and bitumen—a kind of bitumen concrete, in fact—and is satisfactory, though somewhat costly. The conduits are made in 6-foot lengths, and are joined by being placed end to end, a space of about $\frac{3}{4}$ inch being left between. The joint is surrounded with a wooden mould, and a bitumen compound poured in, the ducts being kept open by means of mandrels, as in the Doulton casing. The joints are cooled with water, and set in about ten minutes. The chief drawback to the casing is that, under certain conditions, there is a tendency for the ways to squeeze up and so become blocked.

Wrought iron pipes are very rarely used for distributing mains, on account of their relatively high cost and want of durability, though they are very commonly used for service cables. If employed, they should be embedded in pitch contained in a rough wooden trough, but even with this precaution they rapidly rust away in many kinds of soil.

In laying pipes, certain points must be carefully borne in mind. In the first place, the pipe must be of ample size for the cables to be drawn into it. It is hard to give a definite rule, but for single cables the internal diameter should not be less than $1\frac{1}{2}$ times to twice the diameter of the cable measured over the outside of the insulation, and preferably larger. If several cables are in one pipe, the size of pipe required will depend partly on their number. The following sizes actually used in practice will serve as a guide:—

No. of Cables.	Size of Conductor.	Diameter of each over Insulation.	Size of Pipe.	Remarks.
2	7 No. 14 S.W.G.	$\frac{9}{16}$ in.	$1\frac{1}{2}$	
3	19 No. 15 ,,	$\frac{5}{8}$,,	2	Rather tight fit, 3-in. pipe preferable.
5	7 No. 14 ,,	$\frac{9}{16}$,,	3	
5	19 No. 15 ,,	$\frac{5}{8}$,,	$3\frac{1}{2}$	
5	$\frac{1}{8}$ sq. in.	$\frac{7}{8}$,,	4	
6	$\frac{1}{2}$,,	$1\frac{7}{16}$,,	6	Preferable not to exceed $5\frac{1}{2}$ sq. in. cables.

Care should be taken to lay the pipes as nearly as practicable in a straight line, and, where this has to be deviated from, the curves should be as gentle as possible. If a sharp bend cannot be avoided, a box should be placed at the point, and the cable be drawn out from one of the sections of pipe meeting at the point, and into the other. Cables should never be drawn round a sharp bend. It is even more important to avoid bends in a vertical plane, and on no account should a dip down and up be allowed, as water is likely to collect in the pocket so formed, and is nearly certain to give trouble.

Before beginning to draw in the cables, a swab, fitting fairly closely, should be drawn in to clear out any rubbish or other obstruction that may have been left in.

Where it is necessary to draw several cables into one pipe, it is greatly to be preferred that they should all be drawn in simultaneously. If this is not done, it is usual to attach a rope to the first cable, so that, as it is drawn in, the rope follows, and this rope is then used to draw in the second cable, which in turn carries through the rope for the third, and so on. In practice, it is found that the rope invariably winds itself round the cable which is drawing it in, and when the next cable is pulled in, it naturally tends to follow the course of the rope, with the result that cables drawn in in this manner are inextricably mixed up and tangled. The effect of drawing the rope and the cables over those already in the pipe is often disastrous, the insulating material, in some cases, being cut right through to the copper.

From what has been said, it will be seen that the method with a following rope should never be used. An improvement is effected by 'sticking' for each cable; that is to say, a number of bamboo sticks, coupled by means of screwed gun-metal ends, similar in all respects to those used by chimney-sweeps, are pushed into the pipe, and the rope drawn through for each cable in this manner. This only obviates the tangling and so to some extent diminishes the friction, but there remains great danger of damage. By pulling all cables in at once, there is only the friction against the sides of the pipe to be feared, and some of the cables may be protected from even this by the remainder.

In drawing-in cables, a plentiful and continuous supply of soft soap should be used as a lubricant, but it is essential that it should be perfectly neutral; a white kind, costing about seventeen shillings per cwt., is admirable for the purpose, though expensive.

As regards means for pulling in, it is preferable that a gang of men, pulling directly on the rope, should be employed, as they are more likely to feel a sudden increase in stress if the cable stick; but if the pipes be well laid, and there is no reason to fear sticking, a winch may be used, especially if the cables be many and of considerable weight. The best means of attaching the rope to the cable is to lash the drawing-in rope to it by means of spun yarn, afterwards carefully examining the cable at the point

of attachment, and making good the insulation there, if damaged, or else cutting off the end.

A device often used is a clip attached to a swivel; this allows the cable to twist freely on its axis, but is more apt to let go than a lashing, and sometimes catches in the pipe. If several cables are being drawn in at once, the eyes must, of course, be spaced out so that no two are opposite one another. A short separate rope is then bent on to each eye, and the small ropes securely spliced to the main hauling rope. In this case, also, each cable may, with advantage, have a rope lashed to it.

Great care should be exercised not to put a twist on the cable in handling it, and this is specially important when dealing with concentric cables. If a cable has to be drawn out of a pipe, preparatory, say, to being drawn into another at, for instance, a sharp bend, it should never be coiled down like a rope, but should either be wrapped on a drum or be paid out into a 'figure of eight.' In either of these two ways the cable will enter the next pipe without twist when it is drawn in.

The ends of pipes are exceedingly liable to damage the insulating covering by the sharp edges they present, and the point where the cable enters the pipe must be carefully watched. After the cables are laid, there is still danger that the weight of the cable may cause it to cut where it rests on the edge of the pipe. To obviate this, the Author devised the 'protector' shown in fig. 61. This is often made in two halves, with ground edges on the horizontal joint, so that the protector may be fitted after cables have been drawn in. The protector is fixed in the socket end by means of cement; if a spigot end has to be treated, the end of the pipe is left a few inches short, and the protector butted against it, being held in the side of the junction box by means of cement.

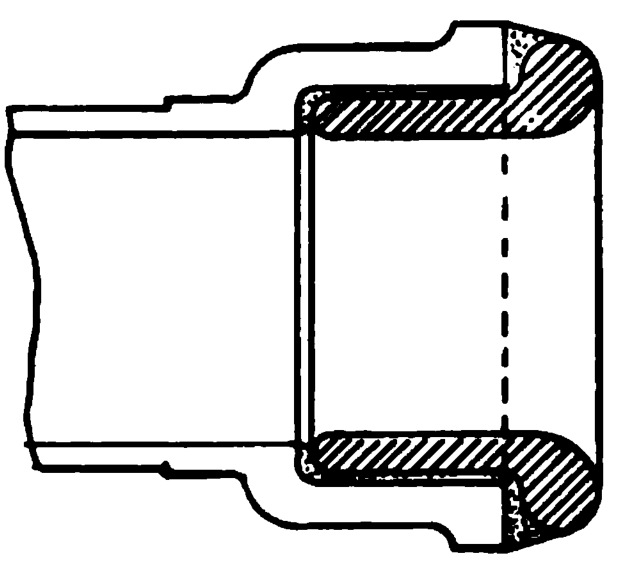


FIG. 61.—Cable protector.

With all drawing-in systems, it is usual to employ special boxes at the points at which T-joints are made. At one time, it was a common practice to put such boxes between every two houses, or at such points as seemed likely to be points of connection for service mains. It is usually found that such pre-arranged points are extremely inconvenient when consumers have actually to be connected, and their use involves unnecessarily long service leads. Hence, some boxes are so constructed that they can be inserted with more or less ease, after the pipe is laid, by cutting out a portion of it.

In the Author's opinion, such boxes are unnecessary and inconvenient, and, unless they are made of inordinate dimensions, it is difficult, and sometimes impossible, to make satisfactory joints on the cables in them. It is

far preferable, if the pipe be of cast iron, to cut out a sufficient length, or, if it be of earthenware, to break out one pipe, to make the joints on the cable, for which there will be unlimited room, since the soil may be excavated below and on either side, and then to build a brick box to bridge over the gap in the pipe, taking care to make good the bottom, and round it like the pipe, so that no water may lodge. This is the chief reason why it is recommended to have earthenware pipes 2 feet 6 inches long instead of 2 feet, since the latter length, when the pipe is broken out, hardly leaves sufficient length for the joints to be easily made.

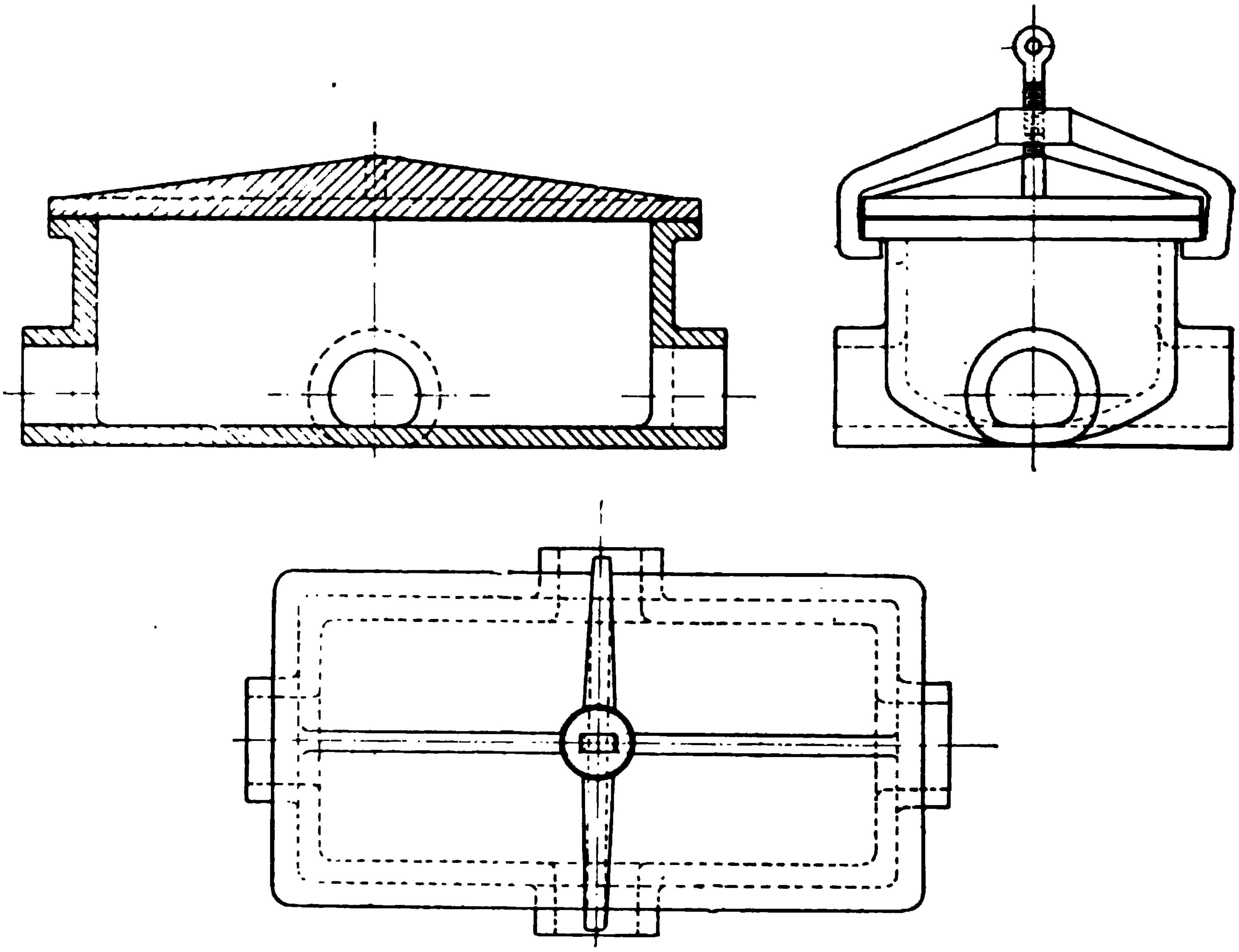


FIG. 62.—Joint box for cast iron pipes.

A box for use with cast iron pipes is shown in fig. 62, and the method of jointing on Doulton casing in fig. 63, a pipe for service cables being shown taken off from a six-way conduit.

The chief advantage claimed for drawing-in systems is that faulty cables can be replaced with ease, and that additional cables can be drawn in if required, so that mains for the ultimate requirements of a given street need not be laid in the first instance. As has already been pointed out, these advantages are quite illusory in the case of distributing mains, for, once the cables have service lines Teed on to them, it is only possible to draw out

quite short lengths, unless the T-joints be cut; and, as regards additional cables, apart from the danger just described that there is of damaging the cables already laid along the pipe, there is the certainty that the service cables Teed on will have their comparatively slender insulation cut nearly or quite through by the new cable. Again, it is much to be preferred that the mains should be of sufficient size in the first instance, as the balancing will be greatly interfered with in a multiple wire system, if each wire consists of two or more cables, unless the conductors of the same polarity be bonded together at frequent intervals. Of course, when separate ducts are employed, the new cables will not damage the others, but the other objections remain.

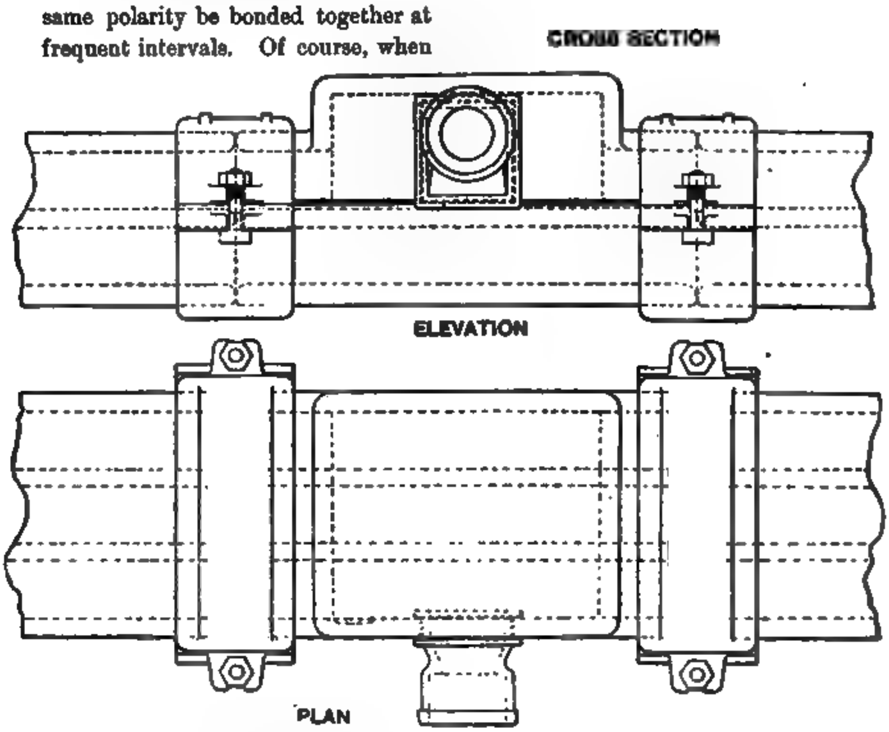


FIG. 63.—Joint box for Doulton casing.

The objections enumerated, however, are not all; a cable laid underground in a pipe is exposed to deteriorating influences of a most serious nature. It is a matter of experience that it is impossible to keep the interior of such pipes free from water. In a long length there is almost

certain to be some weak spot through which water can enter, and, even if the pipe be phenomenally well laid, moisture, in greater or less amount, will condense within it, according to the state of the weather. The result will be that the cable will be alternately wet and dry, and this is a powerful disintegrating influence. If the water were pure, this would be bad enough, but it is usually impregnated with mineral salts, derived from the soil, and with chemical substances arising from the surface of the roadway. In some cases, the chemical reaction may be very strong, and the cables will rapidly deteriorate. In the case of rubber cables, it has been found that Portland cement is fatal to the insulating material, and the Author has abundantly verified this in his own experience; indeed, it may be said that with continuous current, wherever the negative cable touches Portland cement, as, for instance, in the case of a box having its interior rendered with cement, and damp is present, the cable will break down at the point of contact. For this reason, cement-jointed pipes and conduits should be avoided, and cables in boxes should be carefully protected from contact with the walls. Even this, however, will not secure immunity from damage, for the Author has known a rubber cable fail at a point in mid air in a brick box many inches away from the walls or bottom; in this case, there had evidently been a good deal of water in the box from time to time, which had become strongly impregnated with salts derived from the cement, and had risen into contact with the cable and destroyed the rubber.

Another drawback to the system is, that the pipes form a run for rats and other vermin, and the Author has found many cases in which the insulation has been gnawed away; not apparently for food, but because the cables at the particular point have obstructed the passage.

Finally, if a cable break down, and the insulation be burnt out, it frequently happens that the products of the destructive distillation of the rubber and of the tarry compounds in the outer covering form with air an explosive mixture which may ignite and explode with considerable violence.

Taking all things into consideration, it may be said that to lay a cable in a pipe, especially if there be others with it, is to expose it to the most trying possible conditions, and the method is the one of all others most likely to shorten its life.

CHAPTER XIX.

DISTRIBUTING MAINS—BUILT-IN SYSTEMS. VARIOUS DIELECTRICS.

THE conductor may either (1) be insulated throughout with a solid dielectric or with a solid and fluid dielectric intimately mixed, or else (2) with a fluid and a solid at intervals. In the former case, there will be a certain leak all along the conductor; in the latter, if the fluid be air, the insulation will be perfect, except at the solid points of support.

In the first class are included solid materials, such as vulcanised india-rubber, vulcanised bitumen, diatrine, etc., and mixtures such as paper or other fibrous material impregnated with air or light or heavy oil.

In the second class there is less variety, the conductor usually being supported on porcelain, the chief difference in detail being in the method of support, the conductor either merely resting on the supports, or else being tightly strained at intervals.

There is one important essential difference between the two classes: in the first, the insulation resistance is usually high, but the thickness of dielectric is very small, and, if the material is defective, or is injured at any point, there is almost certain to be established a considerable leak to earth; while, in the second class, the insulation is much lower, but the conductor, instead of being liable to leakage throughout its length, can only come in connection with earth at intervals, *i.e.*, at the supports, and the supports are of such a size that the actual distance of the conductor from earth is considerable; even if an insulator entirely fail, there is a good chance that it may not come in contact with earth.

When solid insulation only is employed, the dielectric is usually waterproof in itself; but when fluids are intermixed with the solids, it becomes necessary to enclose the material in an impervious envelope to exclude moisture, and to retain the fluid, if the fluid be a liquid. In the Author's opinion, a waterproof solid is preferable to the mixture, partly because it is less likely to allow water to enter, whether during jointing, or if slight damage be done to the outside of the cable; and partly because the impervious envelope is usually lead, which, being very heavy, increases the

labour of laying, and when laid requires a plumber to be employed whenever a joint has to be made, unless expensive and otherwise objectionable joint boxes be employed. Further than this, the lead being a good conductor, the effects of a fault are often transferred to points at a considerable distance from the original seat of the mischief; while if the two ends of the cable are at points in the earth differing in potential, there is danger of electrolytic damage to the lead.

Turning to the second class, the conductor is usually in the form of strip, since this can be readily rolled up to bring it on the ground, and it may either be supported at frequent intervals on insulators, slotted to receive it, or it may be tightly stretched at long intervals, intermediate supports being provided at a fair distance apart. Unquestionably, the latter method is the best, since the number of insulators can be greatly reduced, while their shape can be made so as to give each insulator a much higher resistance.

Conductors insulated as in the first class may, of course, be used in drawing-in systems, and the special points of each kind in this connection will be referred to when it is described.

One of the most popular forms of built-in systems consists in taking a cable, insulated as in class 1, and covering it with a protective armouring of steel. This armouring is then covered with servings of hemp, or similar material, soaked in preservative compound, and the cable is then laid directly in the ground. Such a cable cannot be expected to be durable, for the steel is as readily attacked as wrought iron piping by many soils, and the protection of the servings is but slight, so that in a few years the insulation of the cable will be entirely unprotected, and may be expected to break down in a short time under the destructive influences to which it is subject.

Various kinds of armouring are employed. The steel may be in the form of flat strips, wound spirally round the cable, two strips being used, the outer being arranged so as to cover the interstices of the inner. This armouring is very stiff, and has a tendency to dent the insulation and sometimes to cut it.

A number of round wires laid up round the cable in one or two layers are to be preferred as being more flexible and less likely to injure the dielectric; but they present a greater surface to the soil, and will therefore rust away rather more rapidly than the strips.

An ingenious method of armouring, known as 'lock-coil,' has been introduced, in which wires, having a section somewhat like the figure 8 instead of circular, are employed. These wires, when laid up, interlace in such a manner as to form practically a tube round the cable. This armouring is very stiff indeed, and is substantially more expensive than the other two kinds, but it is mechanically stronger, and offers more resistance

than they to damage. As a matter of fact, however, no armouring is sufficiently strong to effectually withstand a heavy blow from a pick.

It appears to be now recognised that plain armoured cables laid directly in the earth are not satisfactory, and it is becoming the practice to lay them in a rough wooden trough, and to run in pitch round the cable so as to fill up the trough. Quite recently, earthenware troughs of the form shown in fig. 64 have been introduced. Cables laid in this manner are likely to have a greatly prolonged life, since the armour is protected to a very great extent; but pitch is not a satisfactory material, as it is liable to crack, and so allow moisture to gain access at various points, and in many cases dampness may creep along the armouring; moreover, the cable necessarily rests upon the bottom of the trough, and water may soak through into contact with it.

FIG. 64.—Earthenware trough.

The ideal system of protection for cables from deleterious substances present in the soil is that known as Callender's "solid" system. This consists in laying the cables in troughs of wood or cast iron, and completely surrounding them with Trinidad bitumen. This is accomplished by first spreading a layer of bitumen over the bottom of the trough; when this is nearly set, so-called wooden 'bridges' are pressed on to it at intervals of 18 inches. These are wooden strips about 1¼ inch wide, flat on the bottom, having a semicircular groove cut in the upper surface to loosely fit the cables, the edges being rounded off and carefully smoothed between the grooves; they are boiled in refined bitumen before being used. The bridges adhere sufficiently firmly to the bitumen in the trough to enable the cables to be pulled along the grooves while they are being laid. The trough is then filled up in stages with bitumen until it is completely full, and a cover of wood or cast iron is then put on. Cast iron troughs are extremely durable, but they are expensive, and, if heavy traffic pass over them, they are liable to crack; wooden troughing, if thoroughly boiled in Stockholm tar, free from creosote, is very satisfactory; it is much cheaper than cast iron, will not crack, is much quicker to lay, as it can be obtained in long lengths, and admits of joints on the cable being subsequently made with ease. The most suitable wood is pitchpine, and the troughing is usually made in lengths of about 12 feet, which are joined by being butted together, a larger piece of troughing, about 18 inches long, being placed under the joint. When wooden troughing is used, it is advisable to employ a pitchpine cover about 1½ inch thick, then to put on a layer of dirt, and next

a thin board about ½ inch thick. This upper board serves to warn persons who may be digging that there is something laid, as wood is an unusual material to find; and if a pick be accidentally driven in, the layer of dirt lightens the blow, while the thick board effectually brings up the pick by causing it to stick. When laid under roadways, a layer of concrete 6 or 8 inches thick should be placed over the trough to protect the cables from pressure. A section of a trough, with a bridge in place, is shown in fig. 65. When this system of laying is adopted, there is not the slightest necessity to armour the cables, as the ordinary cable is quite protected from all deleterious influences, except mechanical damage. No system yet devised will thoroughly protect cables from this; the Author has known

FIG. 65.—Wooden trough with cables laid on "solid" system.

a steel pin to be driven right through many inches of concrete, and a 6-inch cast iron pipe into the midst of five cables laid therein.

As regards the exclusion of moisture and chemical reagents, Trinidad bitumen is perfect; it is an entirely inert substance, and is known to have remained unchanged for many centuries; it is sufficiently viscous not to crack and to give with subsidence of the ground, while it is solid enough to keep everything in its place within the trough.

The advantages of this solid system over drawing-in systems will be obvious, and there is the further immense gain that the cables are open to inspection throughout their whole length during laying and after, until the bitumen is poured in; they can thus be examined and tested after they are in position and before the trough is filled up. Incidentally this system, in common with those drawing-in systems in which a separate duct is provided for each cable, enables each conductor to be identified at any point; whereas, where a single pipe is employed, they are tangled together, and the cables must be coloured or otherwise provided with a distinguishing mark.

We have now to consider the dielectric employed to insulate the con-

ductor and form the actual cable. These materials have been classified above, and we will now examine in detail the principal ones in use.

In the first subdivision of the first class, we have solid dielectrics, waterproof in themselves.

Vulcanised indiarubber is the first to be considered, on account of the important part it has played. It possesses great toughness and flexibility, is not heavy, has a very high specific resistance, and cables insulated with it are not bulky; it is waterproof, and is, perhaps, the most convenient dielectric available.

Pure indiarubber is so expensive that it is commercially impossible to make the covering wholly of the material. A thin layer of pure Para rubber is, accordingly, placed next the conductor, partly to obtain a high insulation resistance, and partly as a protection to the copper. Next this is placed a mixture of rubber and other materials consisting largely of oxide of zinc; this layer is known as the 'separator,' and is employed to protect the pure rubber from the action of the next layer, and to give thickness to the covering. Finally, there is a layer of vulcanising rubber, *i.e.*, a mixture of pure rubber, sulphur, and what are euphemistically called 'pigments,' of which French chalk forms a large proportion. The pure rubber is lapped on in two strips, the second covering the interstices of the first, the other layers are put on in different ways by different makers. The whole is then vulcanised together by being kept for a given time at a given temperature, which is usually maintained by means of steam. A chemical change is effected by means of the sulphur; and the material, which was, before vulcanising, pasty and soft, becomes tough and springy, and, if not overloaded with 'pigments,' more durable than pure rubber.

Much skill and experience are necessary throughout the whole process of manufacture, from the cleaning of the raw rubber to the final vulcanising process, and especially in compounding the various mixtures and choosing the ingredients. The utmost secrecy is observed by manufacturers, and, outside their ranks, but little is really known of the process.

The quality of the finished product may vary enormously, for, as will be evident, there is a practically unlimited field for adulteration. It is not easy to be certain of the quality from inspection, but good vulcanised rubber will stretch very greatly without permanent set; it will be difficult to break, shortness of nature is always a sign of bad material; good rubber is very tough when sliced with a knife, bad rubber cuts almost like cheese; good rubber, when cut, appears clean, while in bad rubber small glistening particles can be seen, often in large numbers. The insulation resistance of good vulcanised rubber is high, but an erroneous estimate may be formed if reliance be placed on a test of this alone, because the insulation resistance can easily be increased by putting on a thicker coat of pure rubber next the conductor; obviously, this is no guide as to the quality of the outer layer. It is impor-

tant that the covering should be of sufficient thickness; a good rule for the minimum thickness is 0·031 inch, *plus* one-tenth of the overall diameter of the copper core of the cable.

The outer covering of rubber, when finished, is covered with several layers of tape or braid, or both, well soaked in tar or other preservative compound. If the cables are laid on a drawing-in system, there should be four such layers, and they should be of the best quality, and so treated that they may adhere well to the dielectric and to one another; they will then form a great protection against mechanical damage during laying. These coverings may conveniently be coloured to distinguish cables of different polarity, if laid in a single pipe; and, if there be many, a useful distinguishing mark is to make the two outer layers of one cable tape, and of another braid. This may seem a small matter, but, in practice, it is important, as in case of doubtful identity the Author has known cables to be pricked in order to test their polarity! whereas, if no doubt existed, there would be no temptation to do this.

If to be laid in pipes, the cables, for sizes of conductor up to half square inch, should not be of lower insulation resistance than 2500 megohms per mile for low pressure, or 5000 megohms for high pressure; but, if to be laid solid, they may be of much lower insulation resistance, though the thickness given by the rule named above should not be departed from. The Author has laid one square inch cables of this kind for low pressure work, having an insulation resistance of only 250 megohms per mile, on the solid system, with satisfactory results.

If the cables are laid on a drawing-in system, it is absolutely necessary that the utmost care be taken with every joint. The joint should be insulated first with a good lapping of pure rubber, and over this should be placed an ample thickness of vulcanising strip; that is to say, a material of similar nature to that used in making the cable. When complete, the joint must be vulcanised; this is effected usually by placing it in a cast iron box known as a 'cure,' and surrounding it with sulphur, which is heated to a temperature of 270° to 300° F. for about twenty minutes. The utmost care and cleanliness are necessary, but the process is readily learnt, and, if properly carried out, the joint is as good as the rest of the cable, and actually better, since the dielectric is thicker. The Author has never had trouble from a vulcanised rubber joint; but, if the vulcanising be omitted, a breakdown is certain to ensue. The matter is very different, however, if the cables are laid solid; the joint may be made as before, and the vulcanising omitted, or, instead of rubber, the bitite lapping mentioned below may be employed.

Although vulcanised rubber has so many good points, it cannot be recommended for a drawing-in system. Experience, in many places, goes to show that when so laid it rapidly deteriorates; and the Author, in his own

experience, has found that, under the action of the current, the dielectric is actually decomposed under certain conditions, sometimes very rapidly. The matter is not yet well understood, but, whatever the cause, the process that takes place consists in the formation of minute blisters between the pure rubber and the separator which gradually increase to a very considerable size. The blisters are completely closed, and are filled with a strongly alkaline liquid, which spurts out with great force if the blister be pricked. At a certain stage, these blisters burst of their own accord, breaking through the vulcanised rubber and the tape or braid, and causing an earth on the cable. The cables which suffer are those attached to the negative pole, and the phenomenon is almost certainly connected with electric osmosis. If a rubber cable touch cement, it will speedily break down, the rubber decaying, and a mass of salt containing metallic sodium being formed at the point of contact.

Vulcanised bitumen is a material that has been manufactured for many years, and that is now coming into very extensive use. In many points it resembles rubber; it is fairly tough and flexible, but will not bear nearly such rough handling as rubber; it is considerably lighter than rubber, but, having a lower specific resistance, a somewhat thicker covering has to be used, so that the finished cable does not differ greatly in weight for the two materials; it is entirely waterproof, and is very inert, chemically speaking. Experience, extending over many years, has shown that it is exceedingly durable. For drawing-in systems, it is less strong than rubber, and therefore more susceptible of damage during the process of laying; but, once laid, it is probable that the durability of the cables would be greater, but there is not much experience on this point, since this kind of cable has usually been laid on the solid system.

Unlike vulcanised rubber, vulcanised bitumen is vulcanised before being put round the conductor instead of after. The raw material, which is bitumen dug out of the Lake in the Island of Trinidad, is refined many times until every particle of dirt and foreign matter is completely eliminated. It then goes through a process which the makers do not divulge, and is mixed with sulphur and vulcanised. The resulting material is somewhat porous, and its physical properties are entirely different from those of the unvulcanised bitumen, it being now tough and a solid instead of a viscous fluid. The material is then masticated and squeezed through a die round the conductor, becoming consolidated and free from porosity. A layer of tape soaked in pure bitumen is placed round the conductor before the vulcanised bitumen is put on. The dielectric is then covered with protective tapes and braids, as in the case of rubber. The insulation resistance of conductors insulated in this manner is moderately high, being about 250 megohms per mile for cables up to half square inch. The most suitable way of laying these cables is the solid system, but, as already stated, they may be laid on drawing-in systems with a greater prospect of durability than rubber.

Vulcanised bitumen has a very high melting point, and possesses the great advantage that, if ignited, it does not form a 'torch,' *i.e.*, the fire has no tendency to run along it. There is a popular delusion to the effect that there is a tendency for the conductor to become decentralised in these cables, but this is without foundation; it has probably arisen from a confusion between vulcanised and unvulcanised bitumen, two totally different materials, physically speaking, as has already been explained.

The jointing of vulcanised bitumen cables is exceedingly simple, and is far more speedily effected than that of rubber, calling also for less extreme care. The joint is simply lapped with vulcanised bitumen in the form of strip, known as 'bitite' lapping. This is gently warmed and squeezed together when the various layers adhere tightly together.

Siemens' non-hygroscopic or 'putty' cable is another instance of a cable insulated with a dielectric waterproof in itself, but, in this case, its impermeability is not relied upon, a covering of lead outside it being always employed.

The material is a mixture of various substances, the nature of which is not made known, but rubber and French chalk are ingredients present in considerable proportions. The mixture is rolled into thin strips possessing but very moderate mechanical strength, and is lapped round the conductor. This dielectric possesses exceedingly great strength to resist piercing by high pressure; this is due, no doubt, to there being so many distinct layers, the strips being very thin.

Glover's diatrine cable is not dissimilar to the last described in one of the forms in which it is made. The material is understood to be a residue from the distillation of mineral oils, and, when mixed with certain materials, forms a waterproof material of considerable strength to resist piercing by high pressure, but it is always provided with a lead covering. In this form the material has not been much employed, it being more usual to use it for impregnating fibre, as described below.

The next subdivision of the first class of cables comprises those in which a solid and a fluid are intimately mixed. These are usually known as 'fibrous' cables. The solid is hemp or jute, braided or lapped round the conductor; it is then thoroughly soaked in the hot fluid for a considerable length of time. This fluid is one of the several insulating oils, that most often used being resin oil, in which resin is often dissolved. It does not seem sufficiently generally recognised that this oil should be chemically neutral, but it is essential that it should be so, if the cable is to be durable, otherwise the copper or the lead, or both, may be attacked. Many of the oils used at present are undoubtedly acid.

Diatrine is used as the impregnating material in the most usual form of cables bearing this designation; especial care is taken to ensure this compound being neutral. In the case of diatrine cables, the fibrous material

is loosely braided round the conductor, and the diatrine forms a large proportion of the whole insulating material.

A solid in much favour for use in making these fibrous cables is paper, and its advantages for the purpose are considerable. It possesses in itself, when dry, great resistance to piercing by high pressure, and, since it is applied in many layers, the probability of a weak place extending for any considerable distance radially is not great. Again, when the cable is bent, the different layers slip readily over one another, and there is less danger of the material cracking than if it were stiff.

Before being soaked in the oil or compound, the solid, after having been put on the conductor, is subjected to prolonged baking to drive off moisture. This is a vital part of the process of manufacture, the more the moisture is driven off, the higher will be the insulation resistance; but the high temperature and the long exposure necessary to attain this, have a most deleterious effect on the fibrous material, making it brittle and friable. Hence, it is undesirable to require a high insulation resistance in such cables, it being preferable to tolerate the presence of a fair amount of moisture for the sake of securing mechanical strength in the fibre. For cables exceeding half square inch in section, 50 megohms per mile is a high enough insulation resistance.

It must be borne in mind that remanent moisture is less likely to cause trouble with alternating than with continuous current, and, for this reason, it is probably wiser to specify a somewhat higher insulation resistance for these cables when they are to be used with continuous current than if with alternating.

The insulation of all the cables in this class is more or less hygroscopic, and their insulating properties depend upon the exclusion of moisture, hence they have to be encased in lead. It is important that this should be pure and of ample thickness; a good rule to follow for the latter requirement for cables up to about one square inch sectional area of conductor is to make the thickness of the lead one-tenth of the diameter of the cable measured over the insulation before the lead is put on.

If the cables are to be laid on a drawing-in system, they should be provided with two layers of braiding outside the lead, as a protection against mechanical damage, but, if they are to be laid solid, this is unnecessary.

In order to test whether the drying process has rendered the dielectric brittle, the Author introduced the 'bending-test,' that is to say, a piece of the cable is bent several times in both directions round a drum of small diameter, and then subjected to high pressure. This test is certain to reveal defects if they exist in this portion of the manufacture, and it should never be omitted.

It is evident that this class of cable depends indirectly for its insulation on the lead, and, if this becomes damaged, and water is admitted, the in-

sulation resistance is *nil*. This is a great drawback to cables of this class, for, once water gains admission, it may travel a great distance from the point of entry and so damage many yards of cable. In the same manner, wherever a cable is cut into for jointing, there is danger that through carelessness of the workman the insulation may get wet, and even the humidity in the air may be sufficient to greatly lower the insulation resistance. For this reason, these cables are ill-adapted for distributing cables, which have to be cut into every few yards for the purpose of making service connections, the making of every one of which endangers the cable. Moreover, the joints are not nearly so certain in their results as those on cables in the first subdivision; and, unless a special box be employed, two lead joints at every electrical joint have to be made, and for these a plumber is necessary, unless the jointer can make them, as he is now allowed to do by the plumbers' union.

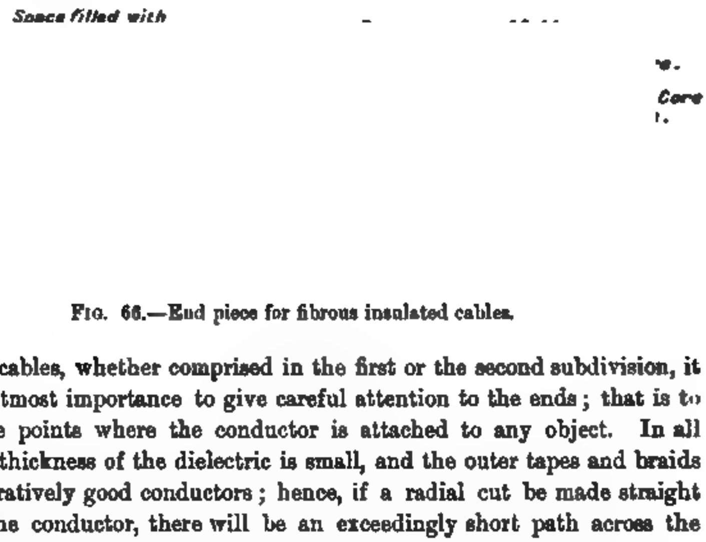


Fig. 66.—End piece for fibrous insulated cables.

In all cables, whether comprised in the first or the second subdivision, it is of the utmost importance to give careful attention to the ends; that is to say, to the points where the conductor is attached to any object. In all cases, the thickness of the dielectric is small, and the outer tapes and braids are comparatively good conductors; hence, if a radial cut be made straight down to the conductor, there will be an exceedingly short path across the surface of the dielectric at the cut, and there will in consequence be a heavy leak. To avoid this with waterproof dielectrics, the braiding should be cut back some 6 or 8 inches, and the dielectric itself pared down into a long cone, and every particle of dirt removed from it. A lapping of pure rubber strip should then be made over the whole surface from the conductor (which should be sweated up solid, so that no damp may creep along the strands) to the braid, and the rubber should then be painted with hard drying enamel. The length across the insulating surface is thus increased from, perhaps, $\frac{1}{8}$ inch to 7 or 8 inches.

In the case of fibrous cables, special end pieces have to be provided, to exclude moisture, and provide a long path for the current to leak over. Such an end piece is shown in fig. 66.

A system of mains, known as Brooks' fluid system, may here be mentioned, though it has never come into extended use, nor is it at all likely to do so, even for feeders and certainly not for distributors. In this, the conductors are lightly braided with cotton, and drawn into a pipe, which is then completely filled with insulating oil, on which a certain pressure is maintained by the pipe being connected to a reservoir giving a certain amount of head to the liquid.

No reference has so far been made to concentric cables. This is a term applied to a cable comprising two conductors, one of which completely surrounds the other at all points. Their manufacture is similar in all respects to that of single cables, and the same dielectrics are applicable. They are used chiefly in connection with alternating and with high-pressure currents. In the case of the former, they are valuable as giving no external magnetic field, and, in the latter, they afford great security to life, as it is impossible to accidentally touch both conductors simultaneously. Triple concentric cables comprise three conductors, the third being placed around the outer conductor of a concentric cable.

Apart from the advantages named, all concentric cables are highly objectionable for distributing mains. They possess, in this connection, the radical defect that, in order to make a service connection to the inner conductor, the outer of a double concentric, or both outers of a triple, have to be completely severed. Not only does this necessitate special devices if the joint has to be made while the cable is alive, as is a prime necessity in distributing mains, involving great risk of accidental short circuit, but every fresh joint introduces a resistance, which, if the work be not thoroughly done, may be considerable, into the main conductor; whereas, on a single cable, every T-joint actually augments the sectional area of the main.

Fig. 67.—Three-core cable.

In order to obviate the objections to concentric cables, two or three separately insulated single cables are sometimes laid up together to form a single cable, brought to circular form by means of yarn, and the whole is then braided over to form a single cable. In the case of fibrous cables, each conductor is insulated in the usual way, but not lead covered. The three are then laid up together within a single lead sheath. In a cable made by the British Insulated Wire Co. the conductors are hammered into a wedge-shaped section, on fig. 67, with a view to diminishing the spaces between the individual cables and making a finished cable of smaller diameter.

With all the cables described, special joint boxes may be, and very frequently are, used. When a fibrous cable and a waterproof cable have to be joined together, they must be used, also where a concentric cable has to

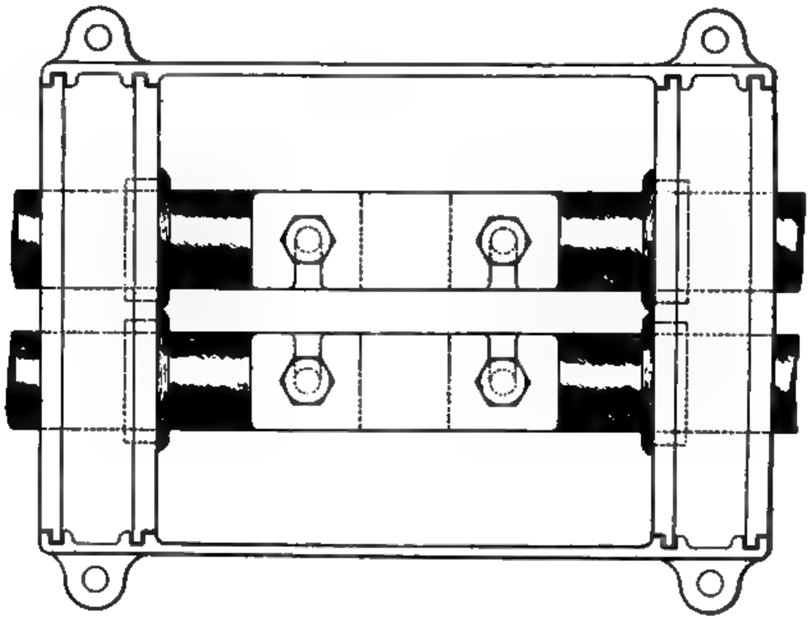


FIG. 68.—Straight-through joint box for two cables.

have other cables of any kind joined to it. Two typical boxes of this kind are shown in figs. 68 and 69.

We now pass on to the second class of built-in systems, *i.e.*, those in which the conductors are supported on solid insulators at intervals, being enveloped elsewhere by air. Since the air is a perfect insulator, it is obvious

that the insulation of a given length of the main will depend on the insulation of each support as determined by its shape and the material of which it is made, and on the frequency of the supports per mile. There are two distinct branches of this system: in the one, the conductors are supported at frequent intervals, the whole stress being vertically downwards; in the other, the intervals between the supports are much greater, and the

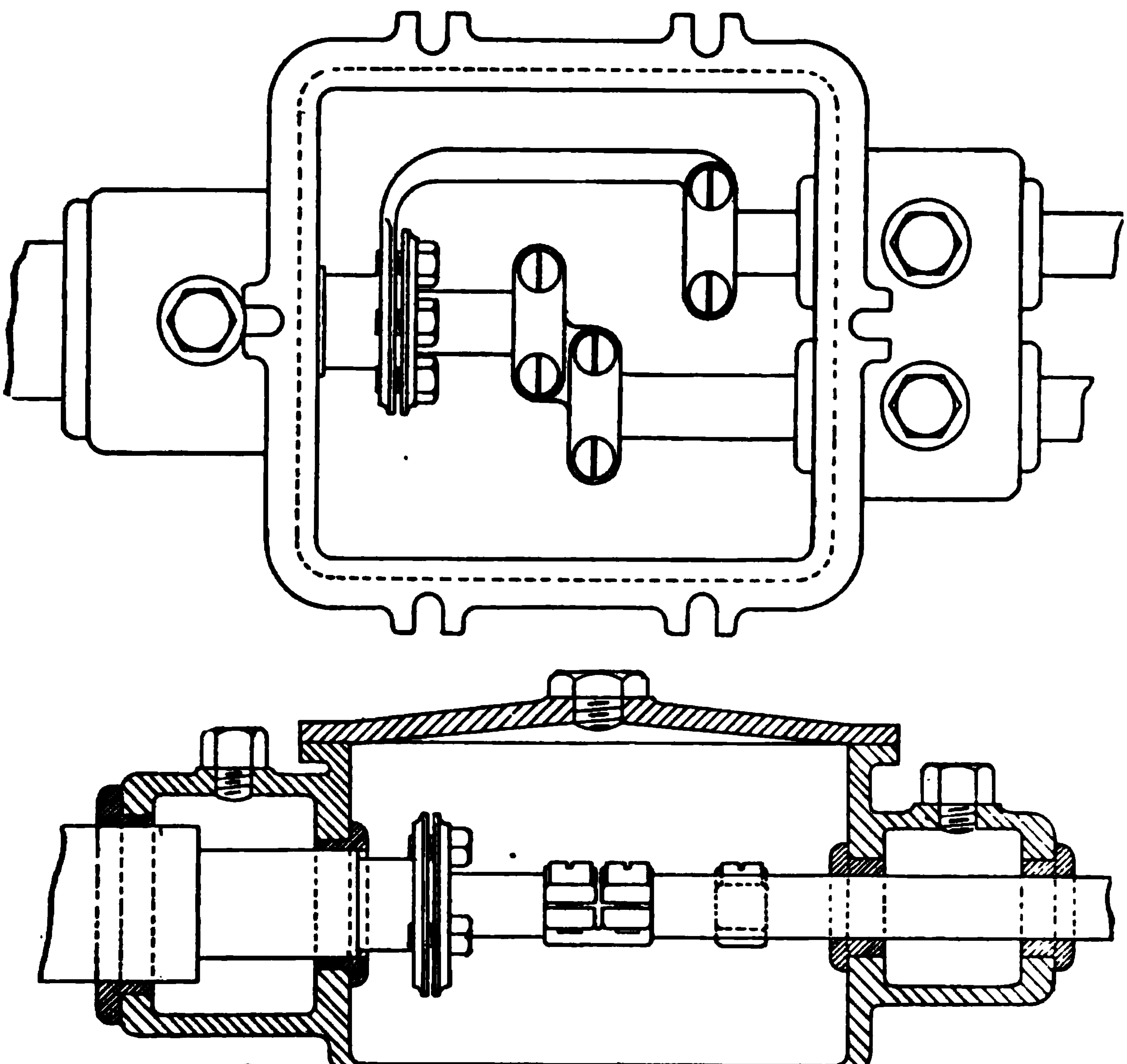


FIG. 69.—Joint box for connecting a concentric to two single cables.

conductors are strained tightly in the direction of their length. In both systems, the most convenient form for the conductor is a flat strip, and this is always used. The supports are fixed in a conduit of some kind. Cast iron troughing, with cast iron covers bolted on and made water-tight with red lead and yarn, has been tried, but is unsatisfactory, and has now been practically abandoned. Earthenware troughing has been suggested, but has not come into any extensive use. Undoubtedly, the best conduit in all respects is one formed of concrete composed of three parts of broken stone or hard brick, two parts of gravel, and one part of cement. The walls

should be about 6 inches thick and the bottom 3 or 4 inches thick. A trench, equal in width to that of the culvert measured outside the walls, is excavated, and boards are put in to form the inside surface of the wall; the concrete is then rammed in between the boards and the side of the trench, the outer side of the wall thus taking care of itself and following the unevenness of the ground. When the concrete has set, the boards are withdrawn and the bottom is put in, the walls having been made of sufficient

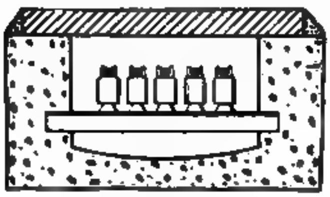


FIG. 70.—Section of culvert with strained copper showing supporting bar.

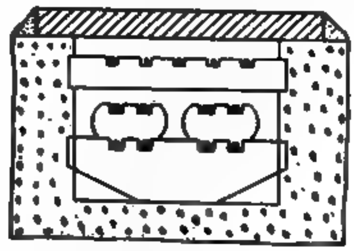


FIG. 71.—Section of culvert with unstrained strip showing insulators.

height to allow of the finished culvert being of the proper depth when the bottom is in. The best section for the culvert is shown in fig. 70, the rounded bottom allowing any water that may get in to go to the middle, thus keeping the sides dry. The whole of the sides and bottom are plastered with one part sand and one part cement, so as to render them water-tight. It is essential that there should be no pockets in the culvert; it should have a continuous fall either from one end to the other, or both ways from the middle or some other intermediate point. The culvert is covered by means of York flags, well bedded on the top of the walls. The joint between two adjacent flags is made by placing a slate beneath their edges and filling the interstices between them with cement. It is most important that the flag should be somewhat narrower than the culvert as shown, so that cement may be placed along the edge; if the flag overhang the wall, it is impossible to make a water-tight joint.

We may now consider the first method of running the conductors, namely, that in which the conductors merely rest upon the supports. One way of carrying out the system is shown in fig. 71. Here a porcelain insulator, notched on its upper surface with a notch for each conductor, is fixed across the culvert, its ends being embedded in the walls. One such insulator is fixed at every 6 feet, and the strips are laid on edge in the grooves. They are tightly strained up from the ends, and, if more than one strip be used to form a conductor, the strips are flattened by means of a special pair of pincers and clipped together by means of gun-metal clips, shown in fig. 72. They are then wedged into the

FIG. 72.—Clip.

grooves by means of wooden wedges driven in while the strips are under tension; wedging is started from the middle of the length, those towards one end pointing one way, and those towards the other in the opposite direction. When the stress is removed, the wedges thus tend to tighten. As an additional safeguard, a so-called 'jockey' is placed midway between two adjacent insulators. This is similar to the other insulators, but is notched on the bottom surface, and does not touch the sides of the culvert.

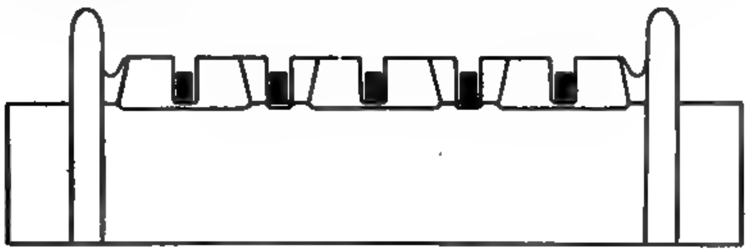


FIG. 73.—Notched insulator giving good insulation from earth.

This system gives fair insulation, which does not appear to become impaired by time, and is generally satisfactory. It necessitates the culvert being open throughout its length while the conductors are being placed in position, and it is not possible to put in new or additional conductors without reopening the culvert along its whole length. The insulator shown in fig. 73 was devised by the Author to improve the insulation to earth, which it did materially, but the form is an expensive one to make.

Another modification of this system is to let the insulators rest on the floor of the culvert instead of placing them across from side to side. The insulators are notched as before on the top, and the strip may either be placed on edge and wedged up, as above described, or it may be placed flat on the bottom of the grooves. Any system in which the insulators are placed on the bottom of the culvert is radically bad, for the insulators block up the passage, so that, if any water enters the culvert, it cannot get away, but collects round the insulators, lowering the insulation to a most serious extent. The utmost trouble has been experienced with mains laid in this manner, the insulation becoming in some cases so low that large leakage currents have flowed, causing much electrolytic action, and the formation of salts and even of metallic sodium. The trouble has been further augmented by this sodium decomposing water brought into contact with it, the heat evolved igniting coal gas present in the culvert.

FIG. 74.—Porcelain insulator.

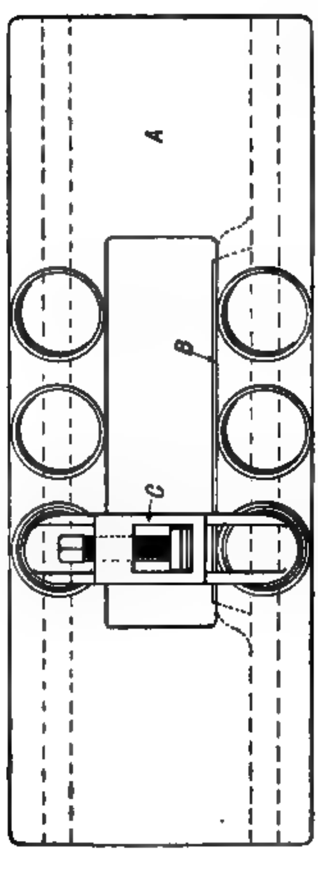


Fig. 75.—Three-way Crompton straining bar.

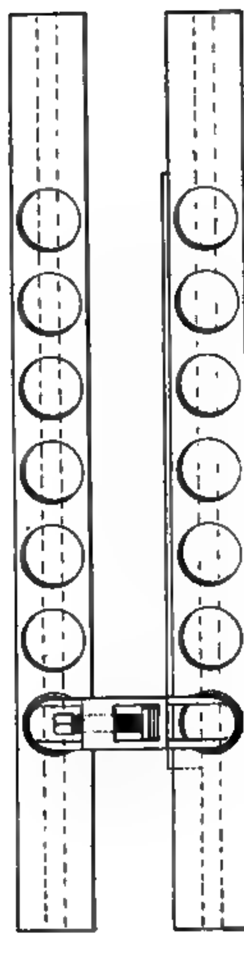


Fig. 76.—Seven-way Crompton straining bar, heavy pattern.

We have now to consider the second method in which the strips are permanently strained in the direction of their length. There is only one system of this kind, viz., Crompton's system, and in this all the drawbacks to the other methods are completely eliminated.

The strips are placed flat on the insulators, and are gripped at the two ends between heavy gun-metal 'bridges' with phosphor bronze set screws. These are ordinarily carried on cast iron straining bars fixed across the ends of the culvert which may be of any length up to 100 yards. They are insulated from the bar by means of porcelain insulators of the form shown in fig. 74, rubber pads being placed in all cases between the metal and the porcelain. The whole straining bar is shown complete in fig. 75. Where the number of conductors is large, and where the section is very heavy, the frame of the straining bar is made of two steel girders of railway rail section: a seven-way straining bar of this type is shown in fig. 76.

FIG. 77.—Double shed insulators.

At intervals of 15 yards, 'supporting bars' of cast iron, enamelled all over in their latest form, are fixed across the culvert about $1\frac{1}{2}$ inches from the bottom. They are of T-section, and from the upper surface project cast iron stalks, also enamelled, one for each conductor, on which are slipped double shed insulators of the form shown in fig. 77, a rubber cap being placed over the top of the cast iron to act as a buffer. The supporting bar itself is shown in fig. 78. On these insulators is placed a gun-metal cap, on

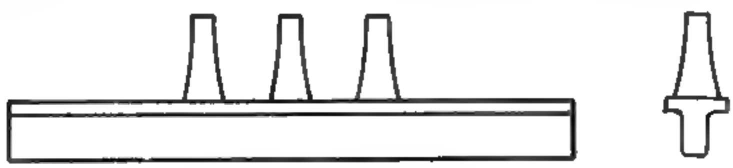


FIG. 78.—Cast iron supporting bar.

which rests the conductor. Owing to the strips being laid flat, and to their being under considerable tension, the conductors are very rigid and no jockeys are necessary.

The straining bars are placed in manholes, and a small box cover may be placed over each supporting bar, or they may be flagged over; the former is probably the better course. In either case, the culvert can be completed, and the conductors drawn in afterwards, openings being required only at the supporting bars. This is a great advantage, and the section of the

conductors can be increased at any time by drawing in additional strips, if the T-joints be taken off.

The small number of supports, and the excellent form of the insulators, renders the insulation extremely high, and this kind of distributing main is, in the Author's opinion, by far the most satisfactory that has yet been devised for continuous current distribution. It is not, of course, adapted to alternating current. The materials of which it is composed are concrete, copper, cast iron, brass, and porcelain, all practically imperishable. For very large conductors it is cheaper than other systems. Services can be jointed on at any point by simply cutting a hole in the side of the culvert for their admission, and clamping them on to the strips; the cost of making service connections is thus much less than with any other system. The security of the system is great, for, the conductors being rigidly fixed a good distance apart and the insulation being absolutely incombustible, there is far less danger of a short circuit than with any continuously insulated system; there is, however, the danger that with very heavy currents, such as those flowing into a short circuit, the electro-magnetic action may cause the strips to swing into contact, or even to leave the supports, but this is rare.

The chief drawback to the system is its bulkiness, it being impossible, in many instances, to find space for it. Another supposed drawback is the danger of flooding: it is difficult to see how the water could get in, but, even if it did, it is unlikely it would reach the copper, as the culverts have so pronounced a fall and are connected to boxes of considerable capacity at both ends which are drained to the sewers. Further than this, even if the copper were immersed, supposing the water to be pure, it is known to be quite feasible to continue running on the main until the culvert can be emptied. The accumulation of coal gas would be a source of danger; but this can be avoided by proper ventilation, which should always be provided.

CHAPTER XX.

DISTRIBUTING MAINS—INSULATION RESISTANCE AND COST.

HAVING now examined in some detail the various systems of distributing mains, it may be well to compare the insulation afforded by them. In the first place, it is necessary to point out that the insulation of a main which has been in use for some time will be very different according as the current supplied through it is alternating or continuous. In the former case, there is no appreciable electrolytic action, but, with continuous current, there is, and the result is a most marked difference in the insulation of the positive and negative conductors. The immediate cause is electric osmosis: this is a phenomenon whereby moisture is attracted to a negatively electrified conductor and repelled from one positively electrified. Thus, if two conductors be connected by means of saturated threads with a vessel of water, and the potential of one be maintained above that of the water and that of the other below, it will be found that moisture will travel along the threads up from the water to the negative and down away from the positive.

The result of this action is that the insulators supporting the negative conductors, or, if continuously insulated, the ends of the cables, become damp, and the insulation resistance in consequence falls. In cases where decomposition of a dielectric takes place, the same phenomenon causes a supply of moisture to be kept up and so facilitates the chemical action. In cases where only two conductors are used, and one may be earthed, as in tramways and high-tension continuous-current feeders, the positive should, of course, always be the pole insulated, and the drying action on this pole is then very valuable.

It is not easy to obtain results of tests made on mains that have been in use for some time, since it is usually impracticable to discontinue the supply through them, but the following is an instance bearing out the above statement as to the effect of the polarity: In a particular case, the insulation resistance of the positive conductor was found to be 161·3 megohms, while that of the negative was only 24·5 megohms. This test was made after the

main had been in continuous use for about five months. The difference of potential maintained between the conductors was 400 volts continuous.

In order to compare the relative insulation afforded by the various systems, it will be necessary to compare that of mains measured before they have been brought into use. In order to show this comparison, the accompanying table has been drawn up. Column 1 shows the description of cable, column 2 the method of laying, column 3 the insulation resistance per mile of the cables when tested under water at the maker's works, column 4 the insulation resistance per mile of the cable after laying in the manner shown in column 2. In each case, the conductor is half a square inch in section, except in the case of vulcanised bitumen drawn into cast iron pipes, the figures for which apply to quarter square inch cables.

1.	2.	3.	4.
		Megohms per mile.	Megohms per mile.
Vulcanised rubber, .	Drawn into earthenware pipes, .	4700	1000
Vulcanised rubber, .	Drawn into cast iron pipes, . .	4700	1800
Vulcanised bitumen, .	Drawn into earthenware pipes, .	150	25
Vulcanised bitumen, .	Drawn into cast iron pipes, . .	150	60
Lead covered paper, .	Drawn into earthenware pipes, .	600	10
Diatrine, . . .	Drawn into earthenware pipes, .	330	470
Vulcanised rubber, .	Laid solid in bitumen, . . .	4700	2200
Vulcanised rubber (low insulation), . .	Laid solid in bitumen, . . .	250	120
Vulcanised bitumen, .	Laid solid in bitumen, . . .	150	260
Bare copper, . .	Laid on notched insulators fixed clear of bottom of culvert, .	...	0·015
Bare copper, . .	Laid on Crompton system, . .	...	4

The cases cited are not exactly means of tests, but are fair average samples taken from actual tests as representative. In the case of the paper-insulated cable, there were a number of straight-through joints on the cable, which accounts in large measure for the low insulation resistance after laying.

It must be observed that the state of the ends of the cables has an enormous effect upon the measured insulation resistance, on account of the surface leakage taking place over them. In the cases given, the ends were always freshly pared and dried, because it was desired to measure the insulation resistance of the dielectric, not the surface leakage; but, even so, in some states of the weather, it is most difficult to obtain the same result as in a factory, where the atmosphere is fairly dry. For this reason the insulation measured after laying is often lower than before, although the cable has not actually deteriorated. In the case cited for the diatrine cable, the figures are reversed, probably because the test was made under exceptionally favourable conditions in the street, or else because sufficient attention was not paid to the ends at the maker's works.

If the ends are left for a few hours, or even minutes, exposed to the atmosphere, the insulation will drop to one-hundredth part of its former value or less. Hence it is seen that the apparently high insulation resistances attained are quite fictitious, since the conditions necessary to yield them cannot be fulfilled in practice. Therefore, although the insulation resistance of bare copper systems is apparently much lower than that of cable systems, it is measured under working conditions, and the difference is thus much less than it seems to be. Experience shows that the insulation of bare copper, properly laid, is far more permanent than that of most cable systems, and it is far better to maintain a moderately high standard than to have an excessively high one, liable to break down with lapse of time.

The cost of any system of mains will necessarily vary according to local conditions, and for each system it will consist of a considerable number of different items. In examining the cost, we will assume that the main to be laid comprises three conductors of ½ square inch each.

In what follows the figures given are approximate only, but will serve as a fairly close guide. The basis is given, as far as practicable, so that altered conditions can be allowed for.

The chief items of cost in every system of mains are: (1) Excavation of trench, including carting and tipping of spoil, and removing obstacles, such as pipes. (2) Providing and fixing conduit. (3) Cable, including conductor and insulation and cost of laying in position. (4) Filling in ground. (5) Making good the surface of the roadway. (6) Junction boxes. No allowance is here made for service boxes. (7) Sundries. These comprise watching at night during progress of work, lighting of cutting at night, and numerous small items.

It is not possible to consider each item separately, so three representative examples will be given of the cost of the complete main.

(1) Vulcanised rubber cable laid in 6-inch earthenware pipe. The pipe is assumed to be laid at a depth of 1 foot 6 inches to the top of the pipe. This will be below most of the gas services and above most of the water services. The cost of the best quality tested earthenware pipe, fitted with Doulton patent joints, is about 1s. 11d. per yard, delivered. The cost of excavating will be about 8d. per yard run, and the cost of tipping about 6d. per load. If the tip is situated at a moderate distance, the carts can make, say, five journeys per day each. The cost of horse, cart, and driver, if hired, is about 9s. per day. The cable, if of 2500 megohm vulcanised rubber, is about £700 per mile delivered, or, for the three conductors, £2100 per mile run. The cost of reinstating is, for York flags, 1s. per square yard; for granite sets, 2s. 6d. per square yard. Each junction box, with 3-wire Pillar Distributor fixed complete, is about £14. Based on actual experience, the cost of all the items, including sundries, works out to about £2700 per mile.

(2) Vulcanised bitumen cable laid solid in bitumen. The cables are assumed to be laid in wooden troughs, with wooden covers, over which a layer of concrete 2 inches to 3 inches thick is placed under footpaths, increased to 6 or 8 inches under roadways. The depth below the surface will be about the same as in the last case, and the cost of excavation, tipping, and carting will not differ materially. The wooden troughing, tarred, will cost about 1s. 6d. per yard. The bitumen at £6 per ton will cost about 1s. 9d. per yard, including the wooden bridges. The cable, having an insulation resistance of 150 megohms per mile, will cost about £500 per mile, or £1500 per mile run for the cables. The cost of reinstating and of junction boxes will be the same as in the last case. The whole cost works out to about £2400 per mile.

(3) Crompton system of bare strip. This being much more bulky than either of the above-named systems, the cost of excavation is greatly increased, and the nearness of the tip becomes of great importance. The same cause operates to make the cost of removing obstacles considerable, as a good many gas and water services may have to be moved. It is assumed that the depth to the top of the culvert, at the highest point, is 1 foot. The crushed stone may be taken at 5s. per ton, the sand at 5s. per load, and the cement at 40s. per ton. Water will cost about 1d. per cubic yard of concrete. The York flags will cost about 4s. per square yard, and the slate for the joints between them about 3¼d. each. The copper, to compare with the prices of cables given above, may be taken at £62 per ton, and the cost of the three conductors per yard run will then be 9s. 6d. The cost of the straining bars and supporting bars works out to 4s. 2d. per yard for culverts 80 yards long on the average, including boxes. The whole cost of such a main on the above basis is about £3200.

In all the above cases the rates of wages assumed are as follows:—

Jointer, ...	8d. per hour.
Jointer's assistant, ...	4½d. ,,
Concretor, ...	8½d. ,,
Plasterer, ...	9½d. ,,
Bricklayer, ...	10d. ,,
Flagger, ...	10d. ,,
Labourers, ...	5d. to 6d. per hour.

It is important to note that an increase in the number of conductors would by no means increase the cost in proportion in any of the three cases, but the increase would be least in proportion in the case of bare copper. Thus, suppose the number of conductors were increased to five. In the first case, the only item increased would be the cost of cable, since the 6-inch pipe would suffice for five instead of three cables. Including laying, the augmentation would be about £1400 per mile. In the second case, a somewhat wider trough would be required, more bitumen and wider bridges would be necessary, the increase in the excavation would be inappreciable,

the chief item would again be the cost of the extra cable. The augmentation would be about £1100 per mile. In the case of bare copper, the increase of cost of the larger culvert is almost inappreciable, since the two walls remain the same and are merely spaced a few inches further apart. The increase in the cost of the straining and supporting bars is about 1s. 6d. per yard. The increase in the number of conductors now only augments the cost by that of the conductors themselves without covering, and hence the proportionate increase is much less with culvert than with the other two systems, the five-conductor main costing about £800 per mile more than the three-conductor one.

From the foregoing comparison of cost, it will be seen that, for the size of conductor selected, the bare copper is the most expensive system of the three, but even in this case, its great durability, cheapness of subsequent service connections, and other advantages might justify its use. For larger or more numerous conductors, as when feeders are laid with distributors, the comparison as to first cost would be altered and the balance would be in favour of bare copper.

CHAPTER XXI

DISTRIBUTING NETWORKS.

HAVING now considered in detail the various kinds of distributing main, we have to see how their size must be determined, and how they must be set out to supply the needs of the district.

It must be recognised at once that, contrary to the case of feeders, mathematical calculation is of no avail, and the engineer has to fall back on his experience and judgment entirely. Seeing that, whatever system of main be adopted, it becomes a built-in one, it is important that the main laid in a given street should be of such size as to provide for the ultimate requirements of the street. This undoubtedly involves extra initial outlay, but, in the end, it is the cheaper course, since the cost of laying is not increased appreciably by augmenting the size of the conductors, and, apart from the saving of the expense involved by opening the street a second time the avoidance of the annoyance to the dwellers along the route and pedestrians is most important.

In order to arrive at a correct estimate of the ultimate demand, the character of the street must be closely studied on the spot, and the class of building carefully noted, also what probability there is of the neighbourhood improving or deteriorating, whether there is a likelihood of additional buildings being erected or of existing ones being replaced.

The density of the demand, *i.e.*, the power required per mile of street frontage, varies enormously, as will be seen from the following table, which gives the result of actual experience, and may serve as some sort of guide.

The proportion of houses taking electric supply varies greatly in different streets, and, of course, will depend, in large measure, on the time the supply has been available; sufficient data are given in the table to enable it to be seen what value may be attached to the figures. A good many of the examples show a very large proportion of houses taking the electric supply.

It may be safely assumed that, as the scale of operations increases, and the price of energy is in consequence lowered, the demand will greatly increase, so that there will be very few houses that are not connected. This applies not only to good-class streets, but to poor neighbourhoods, where there

are shops; for, in the latter, the hours of burning are very long, and it is possible to charge a very low price and yet receive adequate remuneration.

In view of the foregoing considerations, it is much safer to err on the side of laying too large rather than too small a main. It must be remembered that in districts where there is likely to be a demand for power, the carrying capacity of a main is soon swallowed up, even where the pressure of supply is 400 or 500 volts, and estimates based on the demand in streets where energy is taken for lighting only may be very misleading.

It is convenient to have a number of standard sizes of main, not too many, and to lay that one which most nearly approximates to the prospective

Description of Street.	Number of houses in street.	Number of houses supplied.	Length of time supply available.	Kilowatts per 100 yards of frontage.
Main street. Large shops of all kinds, . .	122	112	5½ years	43·0
Main street. Very busy. Large middle-class shops, ...	124	81	4½ ,,	28·9
Main street. Very busy. Large middle-class shops, second example, ...	207	82	3 ,,	16·0
Main street. Large first-class shops, . .	45	37	5 ,,	50·7
Main street. Shops and principal hotels, .	65	50	5 ,,	95·3
Street with warehouses, ...	17	11	5 ,,	14·0
Street with warehouses, second example, .	35	15	3½ ,,	12·9
Main street. Shops and principal theatres, .	55	43	5½ ,,	22·3
Main street. Offices and good shops, . .	42	34	5½ ,,	36·4
Offices and first-class shops. Principal banks, insurance offices, etc., ...	90	63	5½ ,,	33·7
Main street. Shops of moderate size, . .	320	126	3 ,,	7·1
Main road. Large houses standing in their own grounds, ...	22	6	1½ ,,	3·6
Residential district. Chiefly large houses in their own grounds, but partly semi-detached and smaller houses, ...	110	21	2 ,,	1·9
Low-class street. Very small shops, . .	215	13	1 ,,	0·5
Low-class street. Very small shops, second example, ...	300	21	3 months	1·4
Second-class shops, ...	256	28	2 years	1·5

requirements. Thus, reckoning by the size of one outer conductor, half square inch mains are suitable for the densest streets, quarter square inch for busy streets, eighth square inch for side streets, and sixteenth square inch for streets in which the demand is very light. It is hardly ever worth while laying smaller mains than these last, and, unless the pressure of supply be very low, it is rarely necessary to lay larger distributing mains than half-square inch, except in heavy power districts, where one square inch mains may conveniently be employed.

In important streets it is best to at once lay distributing mains on both sides, for it is often difficult to determine which is the more likely to provide the greater demand, and some consumers are almost certain to be obtained on the other side. These can, of course, be reached by crossing the

road, but such crossings should be avoided as much as possible, as they are expensive, and, the service mains being small, are liable to give trouble when laid under roadways where there is heavy traffic. Moreover, a number of crossings complicates the system. In streets where the houses are scattered, the traffic is usually light, and the same objections do not apply. A main on one side only may then be laid with advantage.

In estimating the size of main, it is well to aim at a final current density of 600 amperes per square inch; this is an economical density for the average conditions of supply, and, at the same time, admits of considerable overloading with safety, if the demand exceed the expectations formed.

In multiple wire networks, the usual practice is to make the outer conductors larger than the intermediate; but, when it is remembered how small in any case the size of the intermediate conductors is compared with the total section of the outers, including the feeders, it seems preferable to make all the conductors of a distributing main the same size.

Now, in all except the smallest towns, it is desirable to connect up the distributing mains to form what is known as a 'network,' *i.e.*, wherever distributing mains meet, conductors of the same polarity are connected together. There may be either one large network, or a number of isolated ones.

The argument in favour of one network is very strong. By interconnecting all points as far as possible, and by joining up every street at both ends, there is established, as it were, a conducting sheet on each pole from which current can be drawn, and if the demand is excessive at any one point the supply can flow to that point from all directions. The importance of this is great, for, in spite of great experience, it is impossible, in laying distributing mains, to avoid occasionally under-estimating the demand in a given street. If these distributors are connected at several points to the rest of the network, this is of little moment. Moreover, the area of maximum demand is constantly shifting from hour to hour, and with one large network less copper is required to deal with this than with a number of isolated networks, each of which must be large enough for its own maximum. Again, if the position of the demand has not been accurately foreseen, and the feeding point has not been placed in exactly the right spot, the error is practically eliminated by the network. With such a system, also, there is much less chance of being unable to reach a consumer in case of a fault.

Against these advantages there would be nothing to urge, if one could be certain that the insulation of the mains would always continue intact; but the best of mains will fail sometimes, and the consequences are then much more far-reaching than if there are a number of small independent networks. In point of fact, it is a question of the best means of maintaining continuity of supply. If it were feasible to arrange an automatic cut-off,

whether in the form of a fuse or a mechanical circuit breaker, so as to isolate any section of mains which become faulty, there would be no question that one network is preferable, but, unfortunately, such a system of cut-outs is practically impossible at the present time. For, imagine a complicated network arranged with a cut-out on every section of main, and suppose a short circuit on a given section, this short circuit would allow a large quantity of current to flow for a short time. If all was in order, the circuit breakers on that section of main would be thrown, but, in order to throw these circuit breakers, large currents must have flowed through other portions of the network in order to reach this section, with the inevitable result that the circuit breakers on these portions, which are also set to cut off with extra current, are thrown as well, a dozen cut-outs perhaps going out of several hundred, and there may be but a slight clue as to where these cut-outs are, as the course taken by the current will vary according to the conditions of the load at the time.

Another great difficulty in using cut-outs arises from the fact that if the outer conductors of a distributing main be interrupted between two feeding points, and there are no balancers on the section, the lamps on the circuit or circuits which have the smallest load will be subjected to an undue pressure—this alone is almost fatal to the use of cut-outs.

If the question once be faced that a short circuit cannot be efficiently provided against by means of cut-outs, but has to be burnt out, then the advantages of a large network become manifest, for the relative importance of a short circuit diminishes as the extent of the scale of operations increases. Consider the case of a station supplying half a million lamps, and distributing at 400 volts. When all lamps are alight, their combined resistance between the outer conductors is only about one four-hundredth part of an ohm, and it must be an extremely bad short circuit which has, and can maintain, as low a resistance as this. There is a good chance of burning out a fault quickly if the network will admit of heavy currents being delivered at any point.

It is obvious that with a network so connected up it is out of the question to employ joints which cannot easily be broken. Switches are occasionally employed to effect the connection; but they are very difficult to keep in good order, on account of the trying conditions to which they are exposed underground, and because they are so seldom manipulated.

Many disconnection boxes have been made in which the mains are connected by means of links easily removable. A typical example is shown in fig. 79. Though doubtless convenient enough for jointing purposes, these boxes are not suitable for disconnecting the mains when heavy currents are flowing through the joints; and it is just at such times, *i.e.*, when a fault exists at some point in the network, necessitating the cutting out of a section without interrupting the supply, that the device is wanted. An apparatus

known as a Pillar Distributor was designed by the Author to meet these conditions. It admits of very heavy currents being safely interrupted; thus, in one case, 1700 amperes at 200 volts was broken, and in another the current flowing at a pressure of 150 volts through a dead short circuit was also successfully broken.

VULCANITE SUPPORTS SCREWED INTO COPPER

FIG. 79.—Disconnecting box with links.

The apparatus consists of a central cast iron pillar, supported by three insulators, and is fixed in junction boxes. The pillar carries a cast iron plate for each pole; thus, in three-wire distribution there are three plates, or, in five-wire, five plates. On each plate is fixed a ring-shaped insulator of porcelain carrying a gun-metal ring having projecting studs to which cables can be

clamped by means of nuts, the ends of the cables being sweated into lugs. A large funnel is slipped into the top of the pillar, and serves to collect any water that may drip into the junction box, and so prevent it from falling on to the apparatus. The water runs down the funnel through the interior of the column. Fig. 80 shows the apparatus complete for three-wire distribu-

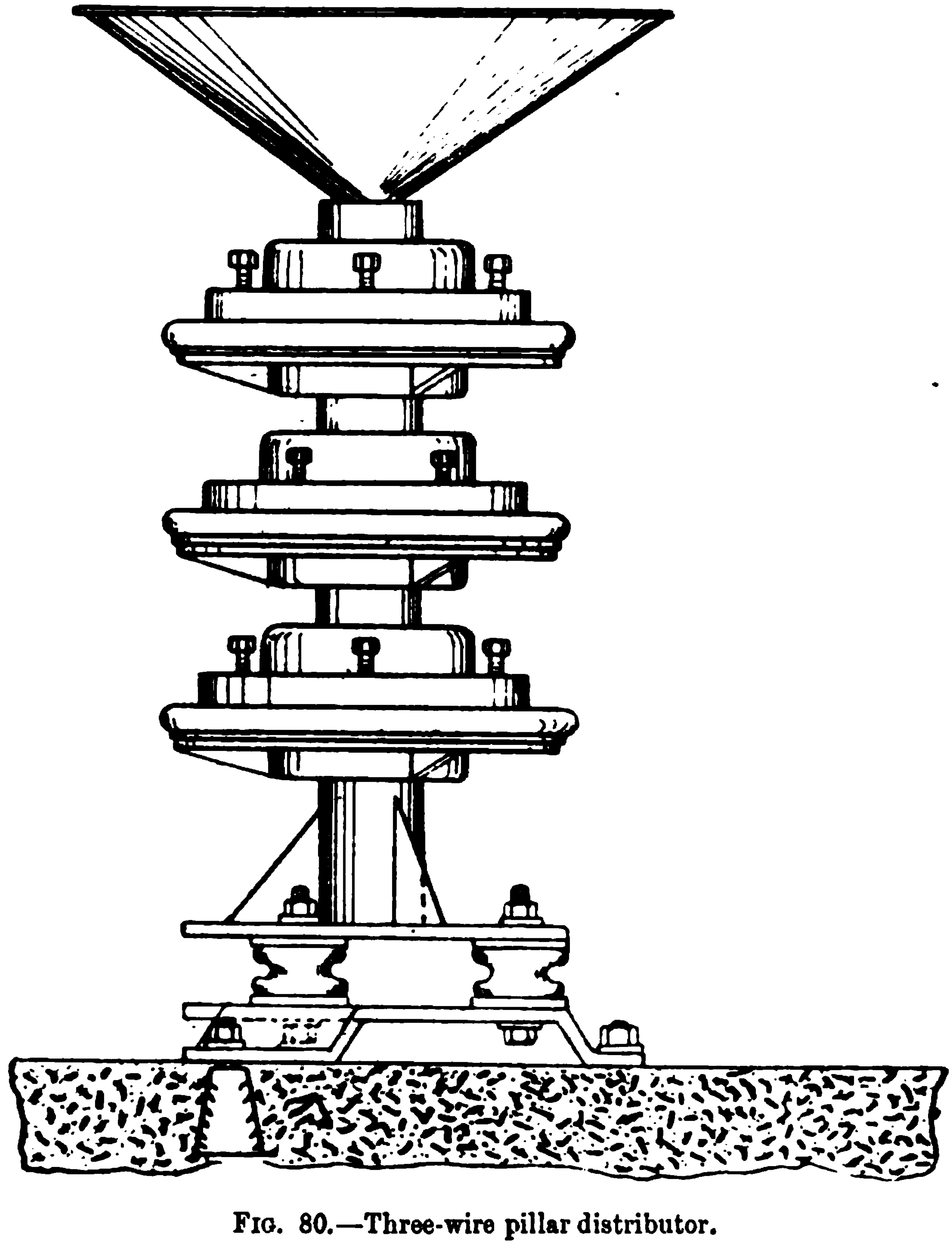


FIG. 80.—Three-wire pillar distributor.

tion without any cables attached. Fig. 81 is a reproduction of a photograph of a five-wire pillar, and fig. 82 shows a five-wire pillar with the cables attached.

The pillars illustrated are intended for large cables, and will deal with a great many. Thus, in the five-wire pillar each ring can readily have four ½ square inch cables and eight smaller ones attached to it; while, on the top and bottom rings, feeders can be connected. The pillar, as a whole, will thus deal with seventy or more cables.

In another form, the pillar is fixed above ground in a cylindrical cast iron receptacle, access being given by means of a casing made to slide downwards.

Fig. 81.—Five-wire pillar distributor.

The above devices are applicable to those connections which are likely to have to be made and broken. Besides such connections, there are, of course,

a number of permanent joints required to connect together the various lengths into which the conductors are divided for convenience in laying. These permanent connections should all be thoroughly sweated, the joint being, however, made electrically perfect without the solder.

It is not necessary to here enter into the particulars of the method of

FIG. 82.—Five-wire pillar distributor with cables attached.

making these joints. In the case of rubber covered cables laid in pipes, it is absolutely essential that the joints should be vulcanised after being lapped. Lead covered cables may be insulated at the joints by lapping them with prepared tape and then slipping a sleeve of lead over the joint, wiping it on to the lead at both ends, and filling up the interior with insulating compound, or in the alternative a special box may be employed.

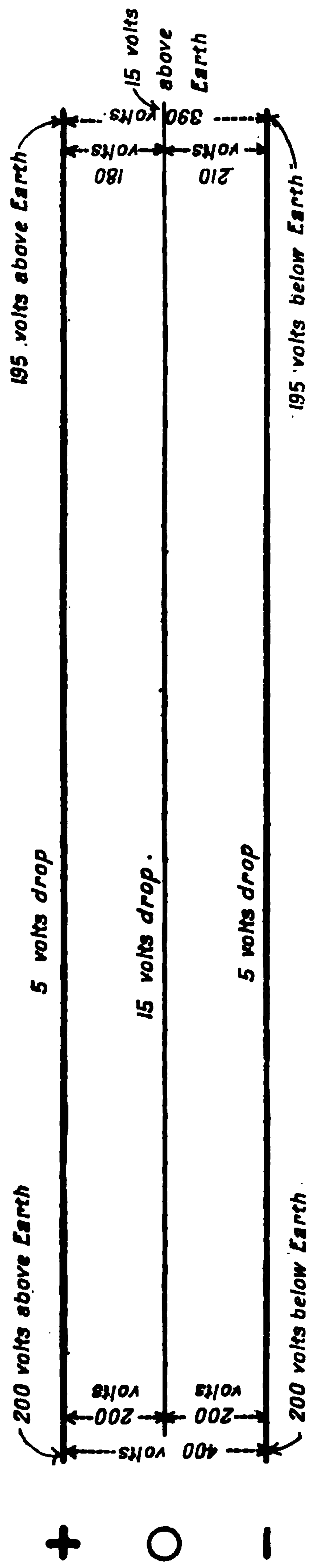


FIG. 83.—Variation in pressure due to want of balance on three-wire main.

The question of 'balancing,' as it is called, in multiple wire networks, may here be referred to. By this expression is meant the distribution of the consuming devices in such a manner that equal currents are drawn from each of the pairs of conductors constituting the distributing main.

To fix the ideas, consider a three-wire main; the conditions obtaining in a five-wire main are similar, but more complicated, and the difficulty of balancing is greatly aggravated. If one side be more heavily loaded than the other, a current will flow down the middle conductor until it can find a path through lamps on the other pair, or be picked up by the balancers. Now, there will be a fall of potential in this middle conductor, and the result will be that the pressure on one pair will rise, and on the other will fall to a corresponding extent.

To make this clear, imagine three conductors, the middle one of which is maintained at earth potential, while one of the others is maintained 200 volts above earth potential, and the third 200 volts below. Now, suppose that at some distant point the distribution of current is such that the fall of potential in each outer conductor is 5 volts and in the middle 15 volts. Obviously the far end of the middle conductor is 15 volts above earth potential. The end of one outer conductor is 5 volts less than 200 above earth, and that of the outer is 5 volts less than 200 below; hence the difference of potential between the middle and one outer is 180 volts and between the middle and the other outer 210 volts (*see* fig. 83).

It is often lost sight of that although the total balancing on a whole system may be good, or even perfect, yet the local balancing may be extremely bad. To take an extreme case, suppose two streets having the same number of lamps in each, but, in one,

all are connected to one side of the distributing main, and, in the second, all are on the other. This would give perfect balancing at the station, but the distribution would in effect be on the two-wire system in both streets at half the station pressure. The balancing current is equal to that in one outer, and has to flow down the whole length of one middle and up that of the other (*see* fig. 84).

The same thing may readily take place on a large network, if total balancing only be aimed at. What is required is to get each street balanced in itself, and, if the street be a large one, each section of main. If possible, it is desirable to go still further, and to cause every installation exceeding a

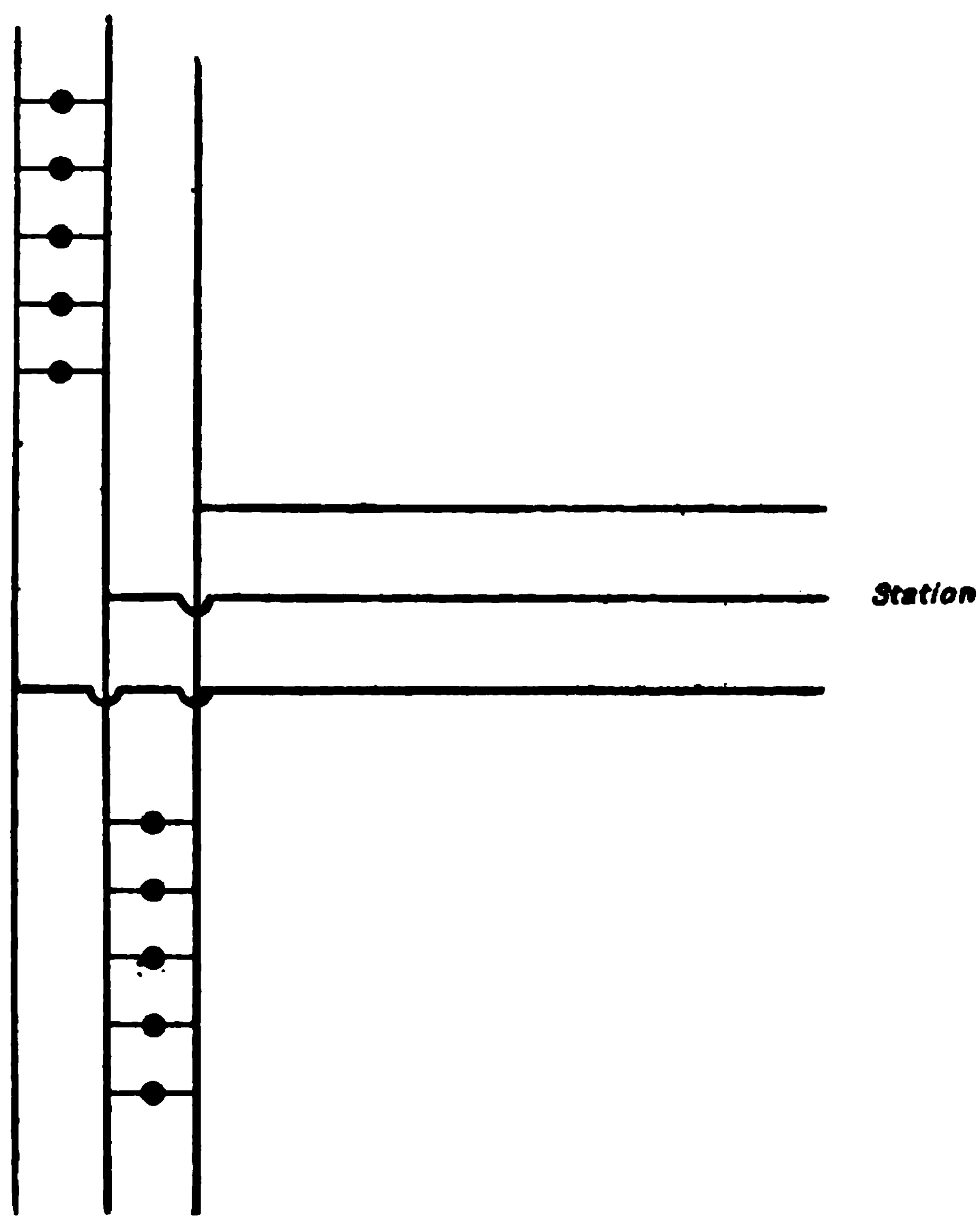


FIG. 84.—Bad local balance giving perfect balance at station.

certain size to be divided and balanced. In balancing, the aim should be to get adjacent consumers on opposite sides of the main, so as to shorten the path of the balancing current along the middle wire as much as possible.

Three actual examples of well-balanced streets supplied on the five-

wire system and one of a street supplied on the three-wire are given below.

No. of House.	Consumer.	+ ⊕	⊕ O	O ⊖	⊖ −
4	Refreshment rooms,	...	...	...	12·8
12	Tobacconist,	...	...	...	9·0
16	Umbrella shop,	...	...	8·6	...
18	Optician,	...	12·8	...	...
	Public-house,	8·2	...	...	...
20	Italian warehouseman,	...	...	6·0	...
	Underground convenience,	...	...	11·0	...
24	Tripe dealer,	8·3	...	...	...
	Public-house,	...	...	...	26·2
	Hair-cutting saloon,	...	1·3	...	...
26	Public-house,	47·0	21·8	18·6	...
	Auction rooms,	...	9·6	...	...
		58·5	45·5	44·2	48·0

No. of House.	Consumer.	+ ⊕	⊕ O	O ⊖	⊖ −
	Tobacconist,	6·4	...	...	...
	Hatter,	...	22·7	...	...
2	Stationer,	...	...	4·5	...
4	Fishmonger,	...	9·3	...	...
8	Jeweller,	...	...	28·8	...
10	Refreshment room,	...	...	...	23·7
12	Fruiterer,	9·0	...	...	...
12	Optician,	...	...	13·4	...
12	Hosier,	...	18·5	...	...
14	Public-house,	30·7	...	...	...
16/18	Tobacconist,	...	...	...	15·0
20	Fishmonger,	25·3	5·0	...	...
22	Offices,	...	5·0	...	...
26	Offices,	...	...	...	19·6
28	Grocers,	...	...	30·7	...
30	Musical instrument dealers,	...	7·6	...	...
36	Offices,	15·3	...	...	...
42/46	Ironmonger,	...	...	...	25·0
	Electrician,	8·3	...	...	...
48	Tobacconist,	...	...	8·2	...
	Furniture dealer,	...	14·0	...	...
		95·0	82·1	85·6	83·3

No. of House.	Consumer.	+ ⊕	⊕ O	O ⊖	⊖ −
23	Tailors,	...	...	35·2	...
25	Offices,	11·5	6·4	...	...
27	Hosiers,	...	...	7·6	30·7
29	Tobacconist,	...	26·2	...	...
31	Offices,	...	...	3·8	...
31	Stationers,	...	...	6·4	...
33	Jeweller,	...	40·5	...	...
35	Offices,	14·9	2·7	5·8	...
35/37	Tailors,	...	...	27·0	55·0
	Branch main,	...	19·8	...	...
39	Tailors,	26·2	35·8	23·0	23·0
41	Offices,	20·0	27·9	27·7	20·0
41	Chemist,	8·6	...	...	...
43	Mathematical instrument makers,	...	16·6	...	...
45	Offices,	2·6	2·6	1·9	1·9
45	Tobacconist,	...	...	24·3	...
47	Shoemaker,	...	...	35·5	...
49	Grocer and confectioner,	...	...	...	9·0
	Branch main,	12·3	9·1	...	...
	Branch main,	...	...	...	15·4
55	Tailor,	29·8	...	...	57·6
55	Restaurant,	...	...	3·8	...
55	Offices,	8·6	...	14·7	...
57	Dining rooms,	...	11·5	...	...
59	Hatter,	...	32·0	...	...
61	Offices,	...	...	14·7	...
63	Rubber and waterproof dealer,	...	...	19·7	...
65	Public-house,	15·0	15·0	8·9	8·9
65	Public-house,	26·0	...	...	...
65	Photo lithographer,	...	...	...	20·0
67	Office,	...	...	...	5·8
69	Chemists,	31·5	...	...	...
69*a*	Office,	7·7	...	...	...
71	Restaurant,	...	24·6	...	...
71	Offices,	...	...	10·3	...
71*a*	Offices,	...	...	4·5	...
73	Tailors,	13·0	13·0	13·0	13·0
73	Tailors,	...	...	...	11·5
	Branch Main,	31·4	25·7	37·8	31·0
75	Brush manufacturers,	27·8	...	...	...
79	Tailor,	...	...	27·5	...
81	Athletic outfitter,	...	19·5	11·5	...
83/85	Tailors,	...	13·4	21·1	26·9
87	Refreshment room,	...	10·0	...	...
87	Grill room,	35·7	...	...	...
89	Jeweller,	...	...	...	26·6
91	Tailor,	60·8	17·3	...	...
	Branch main,	88·0	88·0	52·5	89·8
93	Jeweller,	...	...	...	18·0
93	Restaurant,	15·4	...	...	...
93*a*	Confectioner,	...	12·2	...	...
	Branch main,	10·0	10·0	10·0	10·0
95	Jeweller,	19·8	20·0	...	...
97	Jeweller,	...	...	17·0	...
99	Offices,	39·8	17·6	...	...
99/101	Jeweller,	27·8	41·3	27·3	30·0
105	Chemists,	...	...	37·8	20·0
		534·2	508·7	530·3	524·1

No. of House.	Consumer.	+	O	−
97	Tailor,	3·5	...	
	Branch main,	7·3	23·3	
103	Grocer,	9·6	9·6	
109/111	Baker,	3·2	...	
129	Tailor,	...	1·3	
153	Fruiterer,	5·0	...	
159	Political club,	9·9	...	
185	Draper,	9·6	...	
191	Chemist,	...	4·5	
	Branch main,	10·1	10·1	
215	Private residence,	6·9	6·9	
231	Private residence,	9·1	12·0	
235	Private residence,	26·1	29·3	
	Private residence,	24·2	23·4	
239	Private residence,	12·0	12·0	
		136·5	132·4	

The effect of opening the circuit of the middle wire should be noticed. If the number of lamps on both sides of it is exactly the same there is no effect, but this is rarely the case; if more are on one side, the effect will be that the pressure will rise on the other, and, in all probability, destroy all the lamps on that circuit. A consideration of fig. 85 will show the reason.

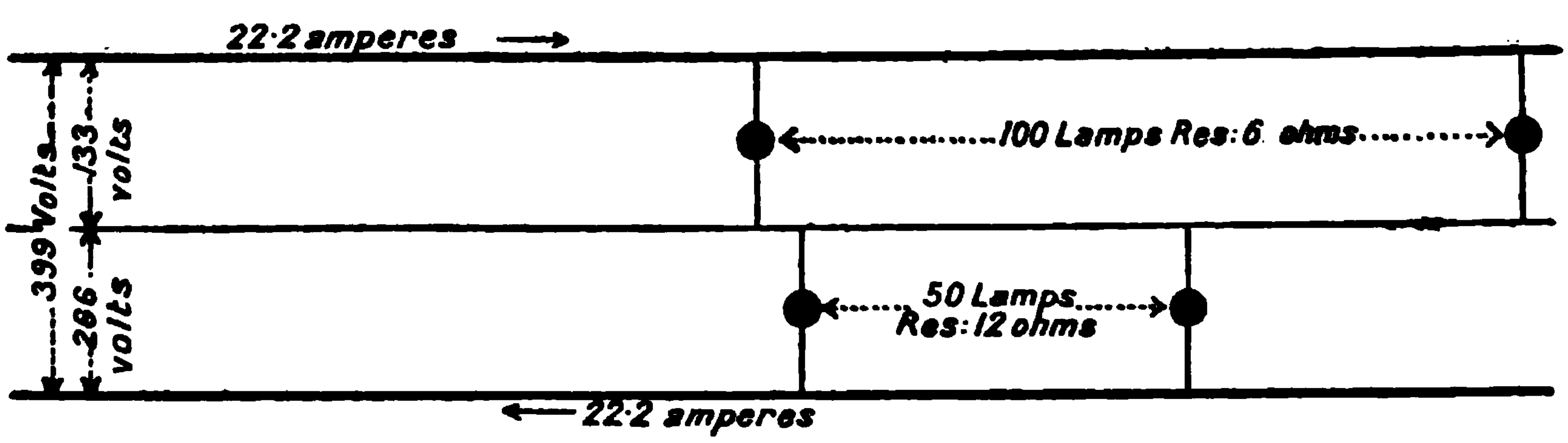


FIG. 85.—Effect of opening middle wire.

Suppose, on one side, there are 100 lamps having a joint resistance of 6 ohms, and on the other, 50 lamps having a joint resistance of 12 ohms. Now, if the middle wire be interrupted, these will be in series on 400 volts. The current that will flow through them will be 22·2 amperes, and the fall of potential through the 100 lamps will be 133 volts and through the 50 lamps 266 volts, *i.e.*, the pressure goes down on the heavier circuit and up on the lighter.

This fact is of great practical importance, for it necessitates much care in preserving the continuity of the middle wire under all circumstances; a fuse must never be inserted in it, and, if connections or disconnections be made on live mains, the outers must always be disconnected first and connected last. This also is the reason why, as stated above, fuses cannot

safely be used on distributing mains between two feeding points, unless there be a balancer on the section, for, if the outer distributors be opened, they cut off the connection with the balancers, and the feeder attached to the portion cut off then feeds the lamps on the two sides in series (*see* fig. 86).

So far it has been assumed that the distributing mains are low pressure, and can be safely handled while alive. It is not worth while to go into much detail concerning high pressure distributing mains, for their great disadvantages are causing them to rapidly become obsolete. Joints are sometimes made on them while alive, but this is a most reprehensible practice and should never be allowed. If, then, it is granted that the pressure must be off the main when a connection to it is being made, it is obvious that the inconvenience to consumers already being supplied must be diminished as much as possible, and, with a view to this, switches should be provided at various points along the main, so that small sections only may be cut out, and every main should be supplied at both ends so that the isolation of one section will not interfere with consumers having installations attached to either side.

High-pressure distributing mains, being nearly always fed with alternating current, were usually made concentric, the most popular system being an

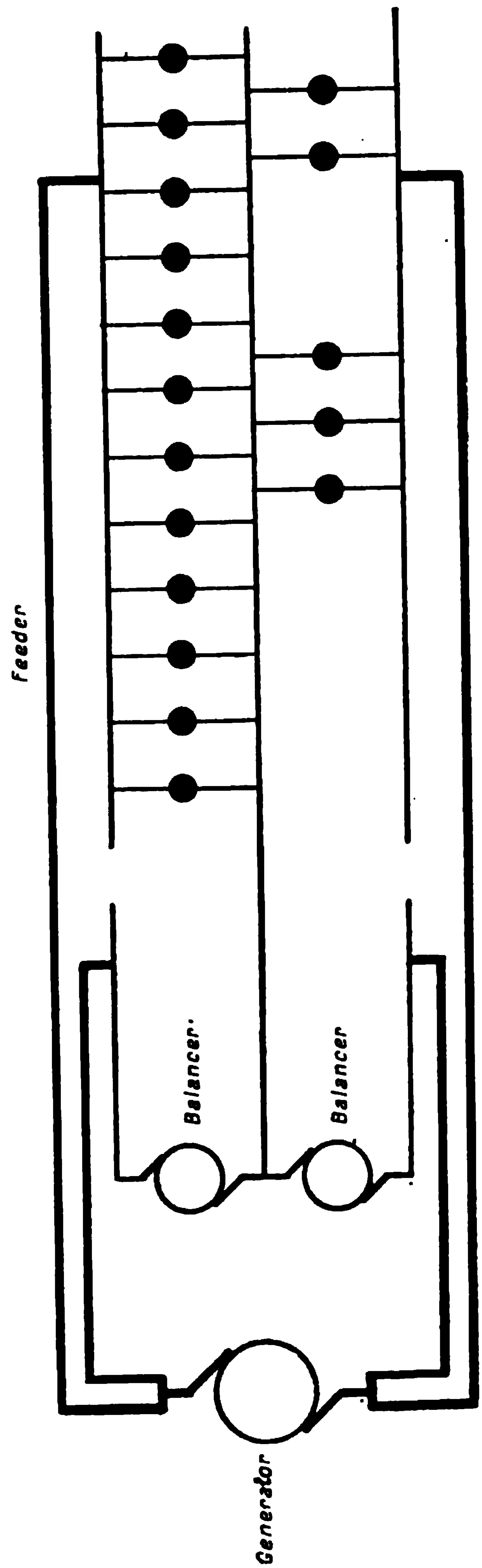


FIG. 86.—Effect of opening outer distributors and feeding section without balancers.

armoured cable laid directly in the ground. The excessive inconvenience of this kind of cable, however, has led to the employment, in a good many cases, of a triple cable formed of three single conductors laid up together, and made circular with yarn, the whole being then armoured like a concentric cable. In a special form of this cable made by the British Insulated Wire Co., the stranded conductors are hammered into the shape of a sector of a circle with rounded corners, as in the cable illustrated in fig. 67. The advantage of this is that the overall diameter of the cable is slightly diminished. In this case, the conductors being insulated with impregnated paper, they are surrounded with lead before armouring.

Again, the fashion of laying the armoured cables directly in the ground is going out, and they are now usually laid solid.

CHAPTER XXII.

SERVICE MAINS AND FEEDERS.

Service Mains.—The special conditions obtaining in the case of these are that, in addition to having to stand being laid underground, they must be capable of being safely handled inside the building into which they are led, and must be protected from mechanical damage when laid therein. Owing to their small size, and the consequent thinness of the dielectric, they are specially liable to damage and decay, and consequently especial care should be taken in connection with them. It may be observed that usually service lines are very short, and hence a fairly expensive main may be put down without unduly increasing the cost per consumer; and it is worth while to do this, to avoid breakdown and consequent interruption in supply.

Service mains are always continuously insulated, no system of bare copper service lines having yet been devised. Owing to the ease with which it will bear handling, vulcanised rubber is very suitable as a dielectric. This must be mechanically protected within the building, and the most convenient way is to have the cable armoured. This armouring is a great protection underground as well, and preserves the cable if it be roughly treated during laying, as small cables are apt to be.

The cables should be laid on the solid system. The complete main used by the Author, and considered by him to be the best, comprises cables insulated with 3000 megohm rubber, armoured with two galvanised steel tapes, the outer covering the interstices of the other, and the whole covered with braiding treated with water resisting compound. These cables are laid solid with Trinidad bitumen in wooden troughs provided with cast iron covers having sides long enough to cover the sides of the trough. A section is shown in fig. 87.

FIG. 87.—Service main.

Another kind of service main largely used comprises vulcanised rubber covered cables drawn into wrought iron pipes. There are, however, several objections to this system. It is extremely awkward, if there are many

bends. The pipe is liable to destruction in certain soils. There is danger of the cables being cut by the edge of the pipe, and the establishment of connection between the consumer's premises and the main pipe or culvert will allow bad smells to enter the house. The decay of the pipe can be avoided if a straight run can be obtained by substituting cast iron or earthenware pipes for the wrought iron. If this be done, however, the cables must be armoured in order to protect them within the houses; this will, at the same time, obviate the danger of cutting the insulating material. If pipes be used, some means must be adopted for blocking the pipe, so as to exclude gas and smells. The utmost care must be used to keep cement away from the cables.

Armoured lead-covered cables laid directly in the ground are largely used; in this case, no additional protection is needed within the house, but exceptional care must be taken to protect the ends.

The cost of service mains will, of course, depend to some extent on the system adopted, but there are a number of items of cost that are necessarily incurred in any case. These are the cost of getting the tackle for doing the work on to and away from the job; of opening, and making good the surface of, the ground; of making the joints on to the distributing mains. It may be well to point out that undertakers are under no obligation to cut through the wall of a consumer's premises, but, on the contrary, have no right to do so, and care should be taken, if the work be carried out, that the work is done at the consumer's risk.

The following table will give a fair idea of the cost per yard run of two important systems of service mains of various sizes, excluding the cost of jointing to the mains:—

No. of Conductors.	Size.	Armoured Rubber Laid Solid.	Unarmoured Rubber Laid in Wrought Iron Pipes.
		s. d.	s. d.
2	7 No. 17 S.W.G.	7 0	4 6
3	7 No. 17 S.W.G.	8 6	5 6
2	7 No. 14 S.W.G.	7 6	5 3
3	7 No. 14 S.W.G.	9 6	6 6
5	7 No 14 S.W.G.	12 3	9 0
2	19 No. 15 S.W.G.	9 6	7 0
3	19 No. 15 S.W.G.	12 0	9 3
5	19 No. 15 S.W.G.	16 6	13 3
3	37 No. 15 S.W.G.	16 0	11 9

The determination of the size of service main is a simple matter compared with that of distributing mains, but, in this case also, judgment is necessary, for the service should be large enough to deal with any probable future extensions. As with distributors, standard sizes should be selected. The smallest size which will be found convenient for low-pressure work is 7 No. 17 S.W.G. for 200 volts and 7 No. 14 S.W.G. for 100 volts; the

section may then be conveniently doubled, a suitable series being 19 No. 15 S.W.G., 37 No. 15 S.W.G. These sizes will deal with most consumers, those requiring larger cables constituting special cases. The same current density as for distributors will be found suitable.

The jointing on of service cables to the distributing mains calls for great care, and the ease and safety with which it can be done varies greatly with the different classes of main, as also does the method. Taking the

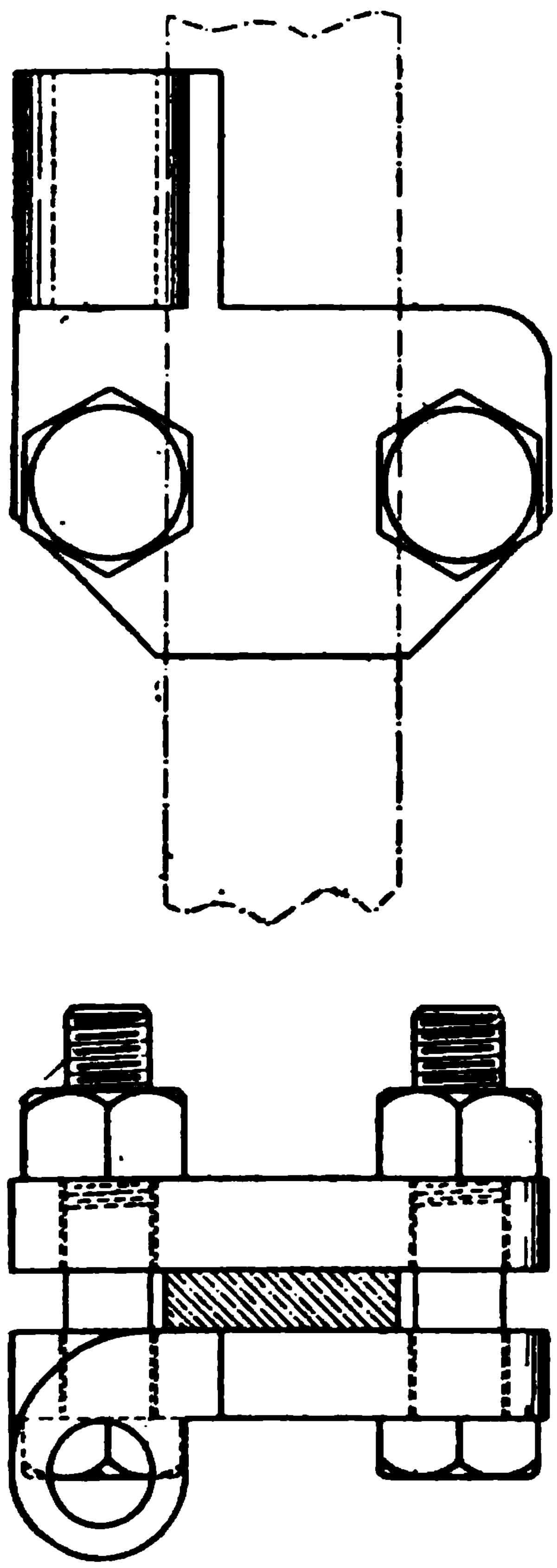


Fig. 88.—Clamps for copper strip service connection.

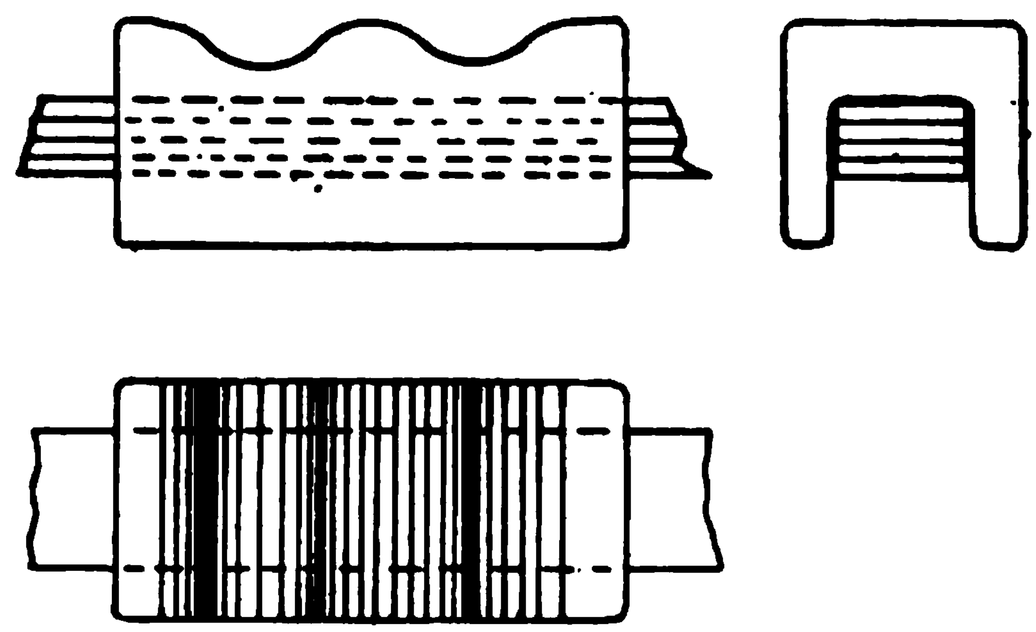


Fig. 89.—Insulator to separate cable from strip.

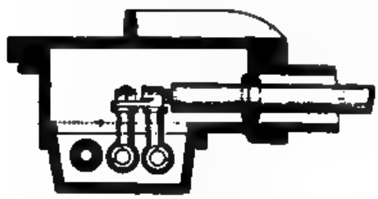
principal sytems of main, the method of making service connections is as follows :—

Bare Copper Strip.—The service cables are sweated into gun-metal lugs, of the form shown in fig. 88, which are placed in contact with the strip. On the other side of the strip a gun-metal plate of corresponding form is placed on each cable, and is clamped to the lug by means of two phosphor bronze bolts. In order to avoid any danger from the insulated cable crossing the strip, an insulator, of the form shown in fig. 89, is provided for the cable to rest on where it crosses the strip.

The practice usually followed is to make these connections at the boxes placed over the intermediate insulators or in a straining box, and at no other place; but when the intermediate insulators are flagged over, no provision is made for taking off service connections at any particular point, the most convenient point for the service to enter the building being selected, and a flag on the top of the culvert lifted at this point. A hole is cut into the side of the culvert, to admit the pipe or trough containing the service cables. The side of the culvert is then made good round this, and, the cables having been run and clamped on, the flag is replaced.

Solid System.—Special boxes may be employed similar to that shown in fig. 90.

An alternative to this is, however, cheaper, and in some respects preferable. The ground is opened at any spot most convenient for the service to be taken off, the concrete is broken away, and the wooden cover and sides sawn so that a piece about 18 inches long may be removed. The bitumen surrounding the cables to which the attachment is to be made



is broken out so as to free the cables, and the cables are then pared, and an ordinary T-joint made, the service cables being sweated on. The joint is then insulated with 'Bitite' lapping, in the manner described for the main cables in Chapter XIX., and is finally lapped with waterproof tape.

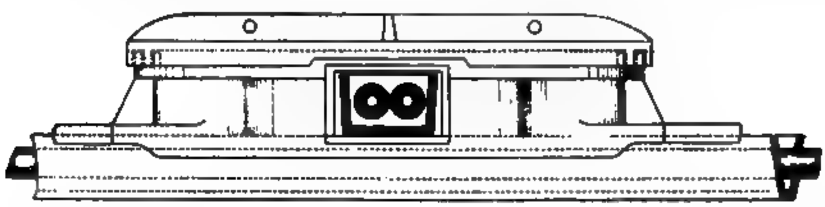


FIG. 90.—Cast-iron service connection box for solid system.

The service conductors are laid in a wooden trough in the same manner as the main conductors. The sides of the main trough are then replaced, or, in the event of very large service conductors being employed, a small piece of troughing, of larger section than the original trough, is slipped under, its sides taking the place of the sides of the original one. The bottom of the service cable trough is cut away, and the sides rest on the main trough, passing completely across it. In this manner, the two service cables

are kept clear of the main conductors. The whole is then filled in solid with bitumen, and covered with a wooden board, which then has a layer of concrete placed over it. The arrangement of the trough is shown in fig. 91.

Rubber Cables in Pipes.—The rubber is carefully removed from the main cable for a sufficient length to enable the service cable to be jointed and soldered on. The rubber is then pared down to a long taper, so as to expose a long clean surface of freshly cut rubber, and the whole surface is

FIG. 91.—Service connection to solid system without special box.

thoroughly cleaned with benzine. Several laps of pure rubber, with a little rubber solution, very sparingly used, are then put on, and over this a number of layers of vulcanising rubber, which is also made to adhere by means of a special solution.

The utmost care is necessary to keep everything scrupulously clean; to remove all trace of braiding or threads from the rubber; to lap the rubber strip on tightly, so as to leave no air spaces; to put it on evenly and thickly in the corners; and to completely cover the pure rubber and the rubber of the cable without including the braiding.

The joint, when finished, is tightly lapped with cotton tape, and placed in a cast iron box or 'cure,' filled with sulphur. This is then heated until the sulphur attains a temperature of 300° F., and is kept at this temperature for about twenty minutes. This treatment vulcanises the rubber on the joint, which should then be as good as that on the rest of the cable, and, being much thicker, more durable. The cotton tape is then removed and the outside lapped with waterproof tape.

These joints are very expensive, a jointer at 8d. to 8½d. per hour, and his assistant at 4d., not being able to make more than two joints in a day of eight hours, but when made they are very satisfactory.

Lead Covered Cables.—Single cables can either be jointed in special T boxes similar to those shown for the straight joints on the mains or directly on to the cables, lead sleeves of T-shape being wiped on, as described in the alternative method for joints on mains. Concentric cables, double or triple, are always jointed in special boxes. An example is shown in fig. 92.

In some cases the service cables are connected to the mains through fuses placed in the joint boxes. This course possesses the great drawback that it is very troublesome to replace a fuse if it go. If it be resorted to, the fuse should be a relatively heavy one, and there should be a second and lighter fuse in series with it in the consumer's house in an accessible position.

Feeders.—The distributing network, constructed as described in a previous chapter (Chapter XXI.), delivers current into the service mains at all points; this current it receives from the feeders which bring the energy directly from the generating station and deliver it into the network at fixed points.

Skill and judgment are necessary in deciding upon the number of feeders and the position of the feeding points. It may be taken that the distributing network is fixed by the demand made upon it by the service lines; the method of feeding it will depend upon its extent and upon the number and position of the generating stations.

In a system of moderate size, with a station fairly central, all the feeders will be low pressure ones. If the generating station be some distance from the network, or if the area be large, the feeders will be high pressure ones, and transformers of some kind will be interposed between them and the distributors. Again, in very large systems there will be extra-high pressure feeders supplying sub-stations from which subsidiary low pressure feeders will be taken.

Hence, feeders may be divided into low pressure and high pressure. Whichever be employed, the calculation of their size stands on an entirely different footing to that of distributors. Here there is no guesswork, for the amount of current to be carried by each can be definitely decided upon and the current density then fixed on economical principles.

In the first place, it must be remembered that the sum of the currents taken away by the distributors from a given point is equal to that which the feeder brings, hence it is of no use bringing a feeder of larger capacity than that of the distributors meeting at the point.

Again, greater uniformity of pressure will be attained by a large number of feeders of moderate size than by a few large ones. In laying out the net-

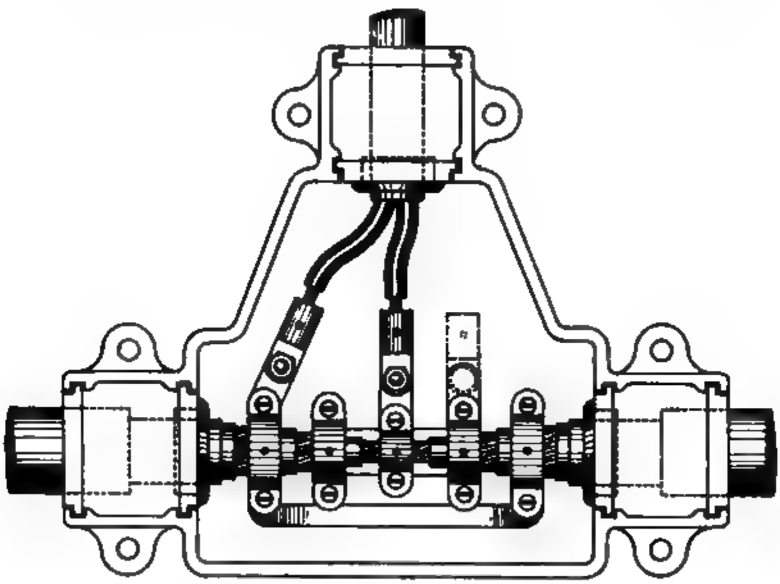


FIG. 92.—Cast-iron service connection box for triple concentric main.

work, points suitable for ultimately becoming feeding points must be provided. These will naturally be at the intersections of streets, so that there will be a good section of copper to take the current away. As the load on the distributors increases, more of these points are connected up to the station, and, when the feeders are numerous, the utility of the large intermediate conductors is appreciated, for, as already pointed out (*see* p. 220), the

disproportion between the area of the outers and that of the intermediate conductors becomes very marked.

Now, as to the current density for the feeders. Thomson's law states that maximum economy is attained when the cost per annum of the energy dissipated in heat, due to the resistance of the conductor, is equal to the annual interest and depreciation on the capital expended on the conductor. In stating this law it is assumed that the whole cost incurred is for the copper forming the conductor, and that the current is constant throughout the year.

These conditions are far from being attained in practice, a large part of the cost of the main being for insulating the conductor and for opening and making good the ground. Furthermore, the current is very far from being constant, varying according to the season and according to the hour of the day.

Now, in applying the law, it is necessary to take account of these items. The capital cost must be taken as the whole cost of the main, including laying, and hence it will be found that a larger conductor can be economically put down than if the cost of the copper only were taken into account.

In calculating the energy lost in the conductor, it is necessary to know how the power varies; this will depend on the nature of the load. In the case of a district in which motors predominate, the energy lost in a given feeder, in the course of the year, will be much greater than if the load consist chiefly of lamps; hence, in the former case, the amount of copper put down must be greater. The loss depends upon the resistance of the conductor and upon the square of the current passing; hence, the rate and mode of variation of the load being known, it is only necessary to find the sum of the instantaneous losses. The section of the feeder thus depends on the mean value of the square of the currents, and not on the square of the maximum current.

It should be observed that under the conditions of practice in which the pressure at the terminals of the feeder nearest to the feeding point and the current to be transmitted are fixed, the most economical sectional area is independent of the length of the feeder; it is, of course, necessary to increase the pressure at the station end to make up for the drop of pressure in the main.

In practice, it is usual to take a certain current density at which to work, this being so chosen as to ensure Thomson's law being approximately fulfilled. Theoretically, the current density should not be constant for mains of different size, since the cost, as already pointed out, is not proportional to the weight of copper. In practice, however, it is convenient to have all feeders of one size, increasing their number in the denser portions of the network, as already stated; hence, little error is introduced from this cause.

The question of whether to feed a given network with low pressure or high pressure feeders is one which has received a great deal of attention,

and given rise to much argument. The subject has been fully considered under the heading of choice of system, and therefore in this chapter we shall only consider the various ways of feeding, without comparing their merits.

Low Pressure Feeders.—These are absolutely simple, and comprise merely conductors connected at one end to the generator, at the other to the network. In feeding multiple wire networks, they may consist either of two wires connected respectively to the outer conductors of the network, or of as many conductors as there are in the network, *i.e.*, three or five as the case may be. With careful balancing, the former is greatly to be preferred on the score of the large saving in copper, and greatly increased simplicity in the generating and switching plant; it, of course, involves the use of balancing transformers. The two-wire feeder is almost universally used in English practice.

Inasmuch as the current density in the main is constant for full load, and is determined from considerations independent of its length, it follows that loss of pressure in different mains will vary with their length, and, since the pressure at their network ends must be constant, it follows that at their station ends it must be varied to make up for the drop. This may be effected in various ways.

The feeders and generators may be of such a size that each feeder will just take the output of each generator, in which case the speed or excitation can be varied to give the desired effect. This system is open to the great drawback that the plant can only be run efficiently at full load, or when the load is so small that the drop is negligible, so allowing a number of feeders of different lengths to be put on one machine.

Another method is to employ batteries, connecting the generators and batteries in parallel and attaching the feeders at suitable points along the battery, switches being employed to vary the arrangements. This is shown diagrammatically in fig. 93. It requires complicated switching gear, and the cells work under conditions difficult to deal with in practice.

Another method, which is coming into considerable favour, is to employ so-called 'boosters.' These are transformers which carry the main current of the feeder, and add to the station pressure the requisite number of volts to compensate for the loss in the feeder; they may either be automatic or variable by hand. The arrangement in the case of continuous current is shown in fig. 94.

This system is very costly, the switching gear is complicated, and a large amount of floor space is taken up by the plant.

Yet another system is to run the plant at the pressure suitable to the longest feeder, and to insert resistances of varying amounts in each of the others. This is an indefensibly wasteful method, but is simple.

In some cases, the current density is varied, the shorter feeders being run at a higher density than the long ones. Economically this is wrong,

but it is better than inserting resistance, since the benefit of the saving in weight of copper is secured.

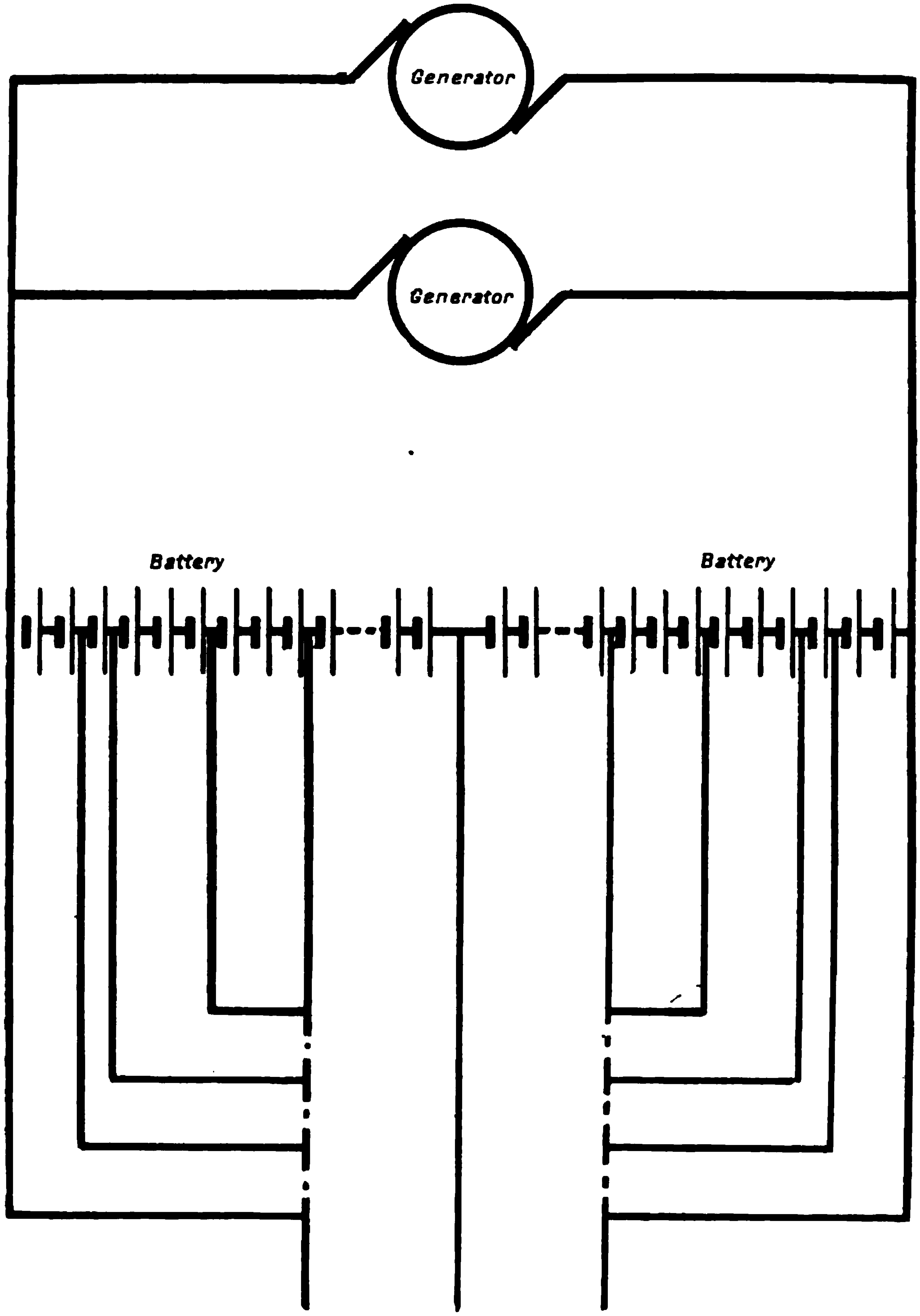


FIG. 93.—Battery system of regulating pressure on low pressure feeders.

On the whole, it would seem that the best solution is to so arrange matters that the feeders are of such lengths that they fall into two or three

groups, and to run these on separate omnibus bars on the switchboard. If a very much interconnected distributing network be employed, it becomes possible, on account of the equalising effect of the network, to give a uniform pressure, even though the feeders differ considerably in length and are run at the same pressure at the station. If there be a few abnormally long feeders, they may best be dealt with separately by means of boosters.

When low pressure feeders are employed in very small areas, as, for instance, in connection with transforming stations spaced, say, a mile apart,

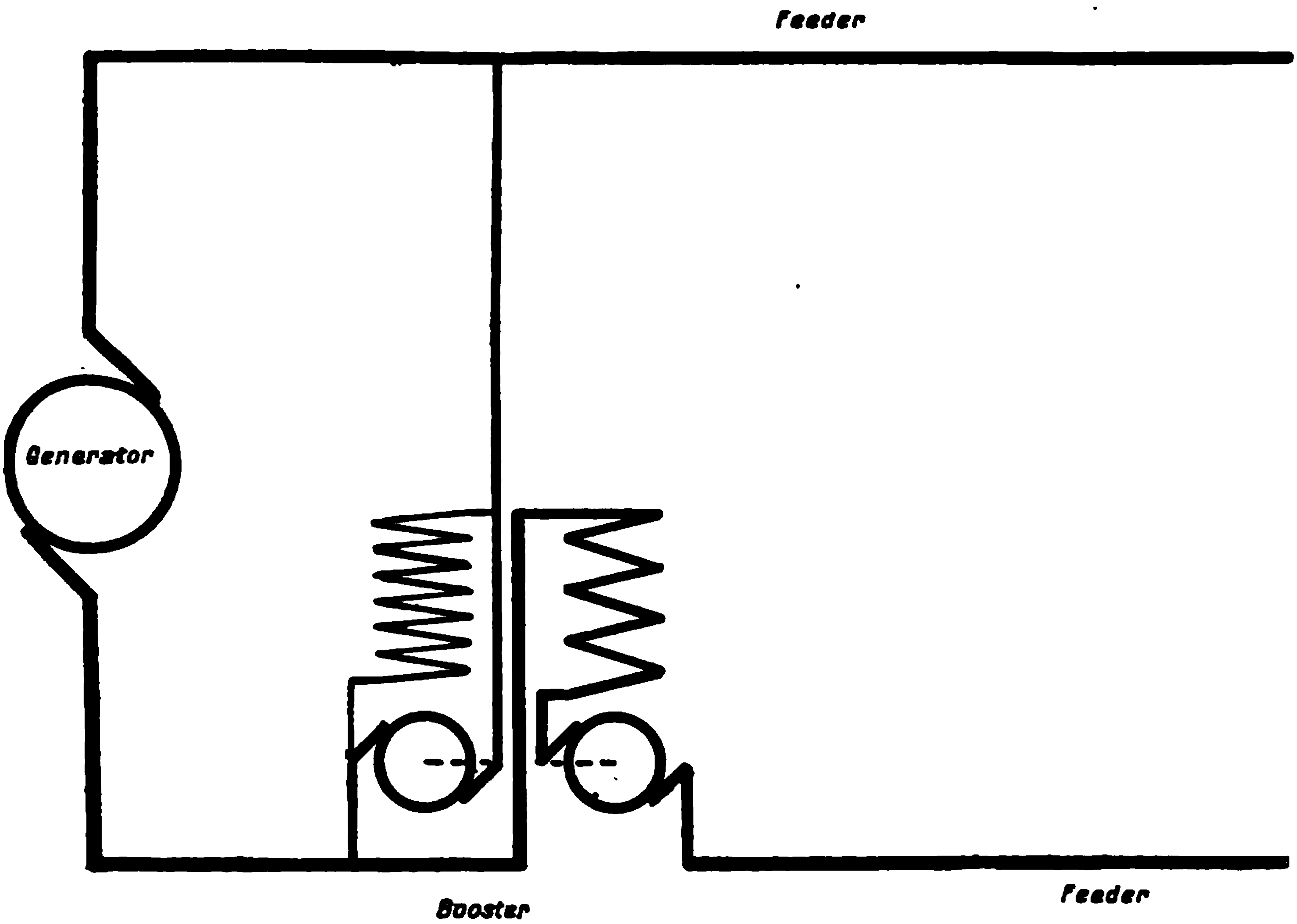


FIG. 94.—Booster system of regulating pressure on low pressure feeders.

and distributing at 400 volts, the problem is greatly simplified, and no regulating devices are necessary.

High pressure feeders may be connected in various ways to the network. If continuous current be employed for both high and low pressure, a number of sub-stations are necessary. These may be made very numerous, and may contain only a few transformers each, in which case, probably, no low pressure feeders will be employed; or the transformers may be grouped together in a few sub-stations, which then become the equivalent of a number of generating stations, from each of which low pressure feeders emanate. This is greatly to be preferred, on the score of economy in the mains, diminished

risk of breakdown, saving in cost of attendance, buildings and land, greater efficiency, and, finally, greater convenience.

If high pressure alternating current be used, the first method just described may be greatly extended, and transformers may be fixed in underground chambers at frequent intervals. If this principle be fully carried out, a high pressure feeder is laid alongside each distributing main, and they are connected through transformers at intervals, these intervals being shorter as the density of the demand is greater.

Though very attractive at first sight, this system is open to great drawbacks. Underground chambers, necessarily cramped in size, are not desirable places in which to fix high pressure apparatus, whether from the point of view of safety to life, freedom from damage to the plant, or ease of effecting repairs. If the fuses controlling the transformers blow, they take a long time to replace, and, finally, in important thoroughfares, it is practically impossible to find space for the chambers, and, even if it can be found, the lids are very inconvenient to the traffic.

It is greatly to be preferred that the transformers should be banked and placed at longer intervals, and, better still, that they should be grouped in a few sub-stations, for the reasons stated above in the case of continuous currents, low pressure secondary feeders being used.

If the high pressure current be alternating and the low pressure continuous, the conditions are practically the same as if both be continuous.

If extra high pressure be used, the current in the feeder will necessarily be alternating; if that on the distributing network be continuous, the only possible arrangement is a limited number of sub-stations, each with low pressure feeders, as all the reasons in favour of this arrangement apply with increased force, especially as regards cost of attendance, the Board of Trade requiring a skilled electrician to be constantly in attendance at each sub-station into which the extra high pressure current is taken.

If the current distributed be alternating, main sub-stations may be used to lower the pressure to high pressure; and high pressure feeders may then take the current to a number of sub-stations, where it is again transformed into low pressure. It is difficult to see any justification for so complicated and expensive a course.

We have now to consider the actual mains to be used for feeders. For low pressure feeders any of the classes of main and systems of laying described for distributing mains are available, but the same objections to some of them do not apply.

Thus, objections founded on difficulty in jointing are absent, since no T-joints have to be made; for this reason concentric cables are admissible, and may even be desirable.

Again, lead-covered cables may be employed with advantage, if care be

taken in making the straight joints connecting the various lengths, and to protect their ends from moisture during laying and the ends of the feeder when laid.

The drawing-in system also appears to full advantage, since it really is a drawing-in system, and cables can be drawn out and new ones drawn in without having T-joints to cut. On the other hand, it is not usually possible to lay several conduits along the same route with a view to subsequently drawing in additional cables, since it is rarely desirable to run several feeders to one point, it being preferable, as already pointed out, to have a large number of feeding points, and hence the cables do not follow the same route.

It must always be borne in mind that a feeder should follow the shortest route, not only in order to save in its first cost, but also to diminish the total annual waste of energy in it.

Of course, all the dangers arising from the exposure of the cables to deteriorating influences in conduits apply equally in the case of feeders and distributors.

The advantages of the bare copper system are greatly accentuated in the case of feeders if it be possible to follow the same course as a line of distributors, or if there be several feeders side by side, for, on account of the heavy section of the mains, the relative cost of the culvert is much diminished.

With high pressure and extra high pressure feeders, the choice of mains is considerably narrowed down.

Only continuously insulated cables can be used; bare copper would not be allowed by the Board of Trade, and considerable difficulties would be presented by surface leakage tending to promote discharge from conductor to conductor.

Dielectric strength, *i.e.*, the resistance to disruptive discharges, becomes of paramount importance. The Board of Trade require that, whatever the insulating material used, its thickness in inches shall not be less than the number obtained by dividing 20,000 by the number of volts pressure, if 2000 volts be exceeded. Rubber has high dielectric strength, so also has vulcanised bitumen; that of paper is exceptionally high, while its specific inductive capacity is low.

For high pressure continuous, and single-phase alternating, current, the advantages of concentric cables are so overwhelming that they should always be employed. When this is done, and the outer conductor is connected to earth, it is practically impossible for any person to get a shock from the cable, and the experiment has even been tried of chopping such a cable in two with an axe while under high pressure, the operator experiencing no hurt whatever.

In the case of three-phase feeders, triple concentric cables do not yield

satisfactory results, owing to the capacity of each conductor as regards the other two not being the same. When the current is used to drive rotatory converters, this is of serious moment, and, to avoid this defect, three-core cables are used. These are similar to those described for distributing mains, consisting of three conductors, separately insulated, and laid up together to form a cable, which is then armoured with steel on the outside. To secure safety, the middle point of the three-phase winding is earthed, as also is the armouring. A section of a three-core or 'clover leaf' paper insulated cable of this kind for transmitting three-phase current at a pressure of 6500 volts is shown in fig. 67.

The most popular method of laying high pressure mains is to armour them and lay them directly in the earth or on the solid system, in the latter case sometimes omitting the armour; the solid system is greatly to be preferred. In the case of extra high pressure three-phase cables, it is well to take the additional precaution of laying the armoured three-core cable in a cast iron trough connected to earth. In order to secure efficient connection between the armour and the casing, the Author uses one gun-metal or malleable iron bridge in each length of casing, secured to it by means of set screws and clamped to the armouring.

High pressure cables should never be drawn into the same pipes as low pressure ones, and should be laid as far as possible from them, and on no account should they be allowed to pass through the same junction box; if this be neglected, there is danger that a man may mistake one cable for another.

Means should be provided for clearly distinguishing high pressure mains from one another, where several run together, at every joint box.

The necessity for varying the pressure on high pressure feeders of different lengths is not so keenly felt as in the case of low pressure feeders, but in certain cases it has to be resorted to. The same devices as were described for low pressure feeders may be employed, and the same objections arise. Of course, the battery method is not applicable to alternating current; when this class of current has to be dealt with, choking coils may be used instead of resistances, and this method is then not so wasteful, though it is still open to objection.

The question of the use of cut-outs on a distributing network has already been discussed; the matter is somewhat different as regards feeders.

In the case of low pressure feeders, it is obvious that if the distributing network has no fuses, and a fault has to be burnt out, the feeders must of necessity carry sufficient current for the purpose, and this practically precludes the use of fuses on them. Moreover, if the insulation of a feeder failed, a fuse at the station end only would not be of any use, since the network would send current back into the fault. The only way to obviate

this is to have a cut-out which will open the circuit when current passes through it in the opposite direction to the normal. Such a cut-out is easy to arrange for continuous currents, but for alternating it is more difficult. A successful device for the purpose, invented by Mr L. Andrews, is described below.

As a matter of fact, it is found that low pressure feeders very rarely give trouble, the insulation of conductors of large size being much less likely to fail than that of small, probably because, when continuously insulated, the covering is considerably thicker, and, in the case of bare copper systems, the weight and rigidity prevent the conductors shifting. The usual practice, therefore, is to run low pressure feeders directly from the station to the network without cut-outs of any kind.

Probably the best practice would be to have a return current cut-out at the end of the feeder nearest the network, and none at the station end. In the event of a short circuit on a feeder, it would be cut off at once from the network, and the ammeter at the station would show which was the faulty main, and it could then be switched out by hand.

High pressure feeders either have a number of isolated transformers connected to them, or they are connected with a sub-station. In the former case, each transformer has its own fuse, so as to cut it out, if it or the circuit supplied by it go wrong, while the feeder itself is controlled at the station by a fuse. When this kind of feeding is adopted, the distributors rarely form one large network, and, therefore, the difficulties described above in relation to low pressure feeders are on a smaller scale, being non-existent in the case of a number of isolated distributors, each fed by its own transformer, since, in this case, current cannot flow back from the distributors into the mains.

By far the most usual course, however, is to have sub-stations, and very frequently each has a separate feeder; while, in the case of a large sub-station, there may be several mains connecting it to the generating station.

In such cases a number of transformers are connected in parallel to one omnibus bar into which all the feeders deliver current, being therefore also in parallel. The ordinary practice is to place fuses at both the generating and sub-station ends of the feeders and on each transformer.

Now, it is obvious that if there be, say, two mains, and one of them becomes short-circuited, current will flow into the faulty one, and blow its fuses at the station end; but in order to blow the one at the sub-station end, the current necessary to do this must pass through the good main, and since the fuses are necessarily all of the same size, it being impossible to foresee which main will fail, the fuses at both ends of the good main will blow.

It is assumed that the network, fed by the large sub-station, is an isolated one; if several sub-stations feed into one large network, the effect will not be so marked, but will be of the same order.

The same remedy as in the case of the low pressure feeders must be applied, viz., a cut-out which will open the circuit when the current reverses its direction, and not when it exceeds the normal.

If, instead of the main itself failing, one of a bank of transformers burns out, the fuse connecting it to the omnibus bar will go, and cut off the high pressure connection. The result will be two-fold. In the first place, this transformer ceasing to contribute its quota of the supply, an increased load will be thrown upon the remainder. If their fuses be light, they will blow; to meet this contingency they should be made very heavy and the transformers be constructed to stand a good overload. The second result will be that the current will be reversed in the low pressure winding, and the transformer will short-circuit the low pressure side instead of the high, the result being the same, namely, the blowing of the fuses on both transformers and mains.

Once more, the remedy is to connect the low pressure side of each transformer to the network by a return current cut-out instead of a fuse.

It is unnecessary to describe the devices for continuous current work, but the one invented by Mr Andrews for alternating currents, already referred to, is interesting for its ingenuity.

The cut-out is actuated by means of a pivoted armature, wound with a fine-wire winding, connected directly as a shunt to the low pressure main to be protected, or through a transformer, if it be a high pressure one. The armature moves in a magnetic field set up by the main current flowing through the feeder.

Now, it is obvious that the current in the shunt winding flows in the same direction, whichever way that through the series winding goes, and that this is true for the instantaneous value of an alternating current; hence, the armature will move in one or other direction, according to the direction of the current in the main coil.

The armature operates a catch which releases a weight that, on falling, breaks the circuit of the main. The catch is of peculiar construction, and is not affected by vibration, while the current of normal direction tends to lock it in its place. Once the armature begins to move in the opposite direction, however, the catch leaves go immediately, there being practically no friction on it.

The device is arranged not to let go with zero current, a certain amount of current in the opposite direction to the normal being necessary to release it.

CHAPTER XXIII.

TESTING OF MAINS.

IT is vitally important that mains should be rigorously tested both before they leave the manufacturer's works and after laying.

It would be out of place here to give detailed specifications for mains. Suffice it to say that every specification should provide for the use of copper of a certain conductivity, which should be measured; for a certain minimum thickness of insulation, or 'wall' as it is called; and for a definite insulation resistance and dielectric strength. The cable, whether it have a waterproof dielectric or be lead covered, should always be tested under water before the outer braidings are put on, and it should be thoroughly dried after immersion; the tests should not be made until it has soaked for at least twenty-four hours. The first test applied should be a high pressure test of, say, 2½ to 7 or 8 times its normal working pressure, applied for, say, half an hour. *After* this, the insulation resistance should be measured after one minute's electrification from a battery giving a pressure of, say, 500 volts.

The insulation resistance to be specified varies greatly with the dielectric used, and must be altered according to the material; it will depend also upon the size of the cable, the larger the conductor the lower the insulation resistance per mile for the same material.

To take a particular case as a guide to the comparative insulation resistance of different materials, a half square inch cable, if insulated with first-class rubber, should have an insulation resistance of 2500 megohms per mile, if with vulcanised bitumen 250 megohms per mile, if with paper 100 megohms per mile.

In order to further test the quality of the dielectric, a breakdown test should be made; this consists in taking a short piece of the cable and bending it backwards and forwards several times round a drum of small diameter, and then applying a pressure sufficient to pierce the dielectric. This should not be less than four times the pressure applied to the whole cable in the first instance. Every length of cable tested should be marked in such a manner that it can be subsequently identified. With lead-covered cables the lead can be stamped; with other cables, one strand may be hammered out flat and stamped with a very small die.

After laying, each length of cable should be carefully tested for insulation resistance after one minute's electrification with a battery giving not less than 300 volts.

By far the most suitable apparatus for this purpose is the portable testing set supplied by Messrs Siemens. It comprises a battery of 250 Hellesen or Obach cells; a reflecting galvanometer with a flat mirror in which is reflected a fixed scale, the image of which is received by a telescope provided with a prism to enable the readings to be taken from above; an ordinary shunt-box and a Wheatstone bridge containing 10,000 ohms; also a condenser having a capacity of 0·5 microfarad.

The whole apparatus is most conveniently arranged in a light covered truck, which protects it and the operator from the weather. The galvanometer is fixed on a table carried by a tripod, which can be let down so as to rest on the ground independently of the truck. With this apparatus a sensibility of about 100,000 megohms per division of the galvanometer scale is easily attained.

With ordinary care, the apparatus never gets out of order. The Author has had such a set in daily use for over five years, the repairs have been practically *nil*, and the original cells appear to be as good as ever.

In making insulation tests, whether in the street or at the manufacturer's works, the utmost care must be taken to have the ends of the cable absolutely clean and freshly pared.

After the various lengths are joined up, a high pressure test should be applied; this need not exceed twice the working pressure, but should not be less. The number of lengths that can be tested at once will, of course, depend on the size of the testing plant.

For this purpose a portable generator must be used. The Author employs an arrangement designed and made to his specification by Messrs Crompton & Co. It consists of a continuous current motor, taking current at 400 volts, and driving an alternator giving a pressure of about 500 volts. By means of resistances in the fields of both machines, the alternating pressure can be varied at constant periodicity, and both pressure and periodicity by speeding up the motor.

The alternator can be directly connected to the testing lead if only low pressures are required, but normally it is connected to a set of three transformers having their low pressure primary windings in parallel and their secondaries in series. Connections are brought out at five points of each transformer, so that a regular succession of steps of 2000 volts can be obtained from 2000 to 30,000 volts. The intermediate values between two steps are got by varying the fields of the machines.

The transformers are contained in a wrought iron box, with micanite-lined cover. The switches are fixed on top of their respective transformers within the box. The primary current passes through contacts on the lid

and sides, so arranged that the act of lifting the cover breaks the primary circuit. It is thus impossible to inadvertently operate the switches while they are alive.

The whole apparatus is mounted in a strong wagon arranged to be drawn by two horses. The motor and alternator are fixed low down; above them, at the front, the transformers; and, at the hinder portion, the switches and instruments. These are mounted on three slate panels.

The first panel, fixed at the back, carries the continuous current apparatus. This comprises two single pole fuses, a double pole switch interlocked with a starting switch in such a manner that the double pole switch can be taken off in any position of the starting switch, but cannot be put on unless the latter is in the off position; the field-regulating switch; a voltmeter reading to 500 volts, and an ammeter reading to 50 amperes.

The second panel contains the low pressure alternating current apparatus, consisting of double pole switch for the alternator; field-regulating switch; and tachometer to show the periodicity.

The third panel contains the high pressure apparatus, namely, voltmeter indicating to 30,000 volts, ammeter reading to 6 amperes, and the high pressure terminals to which the testing leads are attached. The voltmeter does not carry the full pressure, but is connected to a subsidiary winding of the transformers, giving pressures proportionate to the testing pressure. The high pressure terminals are contained within metal shields, and the leads are held by their insulation in clamps, some 8 or 10 inches below, so as to put no stress on the terminals.

Every terminal on the truck is surrounded entirely by a stout gun-metal shield connected to the framework of the truck, and to this are also connected the casings of the transformers and the magnets of the motor and alternator and all uninsulated pieces of metal, the whole being connected to earth when the apparatus is in use.

The set is specified to give 12 H.P. on the test lead at the highest pressure (30,000 volts).

The utmost care should be used in making high pressure tests in the street. The regulations drawn up by the Author for the purpose are given below. They may appear somewhat extravagant, and unnecessarily careful; but surely it is worth while if it save a single life, to say nothing of the money cost for compensation involved by even one fatality.

RULES TO BE OBSERVED IN THE USE OF THE HIGH PRESSURE TESTING SET.

Preliminary.

The use of this apparatus is necessarily attended with extreme danger to life, and the utmost care must be exercised by all persons working with it. The rules given below must be carried out to the letter, and, if this is done, there should be no likelihood of an accident.

It must be borne in mind by the assistant in charge that should a fatal accident ensue, through neglect of the regulations, he will, in all probability, have to answer a charge of manslaughter.

Regulations.

(1) No persons, except those duly authorised, may on any account touch any portion of the apparatus or interfere with any of its parts.

(2) The apparatus may only be used when five persons are in attendance.

(3) The five persons will be numbered as follows, and will comprise the following :—

1. Assistant in charge of apparatus.
2. Junior assistant.
3. Junior assistant.
4. Jointer.
5. Jointer's assistant.

Duties of the above are as follows :—

No. 1 is in charge of the whole series of experiments, and is responsible for the carrying out of the regulations. During the period in which the apparatus is in use, Nos. 2 and 5 will be exclusively under the control of No. 1, and no other person may interfere with them during that time. His position is at the left hand side of the truck, in a position facing the high pressure gauge.

No. 2 is in charge of the starting switch, emergency cut-off switch, and motor field-regulating switch. His position is at the back of the truck facing these switches.

No. 3 is in charge of the alternator cut-off switch, the alternator field-switch, and the tachometer. His position is at the right hand side of the truck.

No. 4 is in charge of the far end of the cable under test. He is responsible for this being properly trimmed and properly safeguarded, and for preventing its being touched. His position is near the end of the cable under test.

No. 5 is to assist No. 4, and take messages between No. 4 and the testing truck.

No length of main may, on any account, be tested without an order in writing signed by the chief engineer requiring it to be done.

The order of procedure will be as follows :—

(4) The testing truck will be taken to the required place, and the horses will be taken out. No test may, on any account, be made with the horses attached to the truck.

(5) The truck will then be carefully levelled by means of the adjusting set screws, so that the instruments point accurately to zero.

(6) An efficient earth connection will be properly made to the earth terminal and to each of the boxes on the ends of the cable.

(7) A guard will be placed round the truck, and danger notices hung up.

(8) If used at night, lamps must be placed round the truck.

(9) Both ends of the cable will be carefully pared by No. 4, and the testing wire attached by him to the cable. The other end of the testing wire will be attached to the high pressure terminal by No. 1, who must see that the ends of the cable and of the testing wire are in proper condition.

(10) The ends of the cable under test must be each enclosed in a metal box connected to earth, and the holes in the ground, or junction boxes, as the case may be, be covered over with boards and securely fenced off. Over the hole distant from the testing truck must be placed the box containing the voltmeter. No person may, on any account, remain in the junction box, or in the trench, as the case may be, while the test is being made. The metal boxes and voltmeter box must be fixed by No. 4, who must see that everything is safe, properly connected up, guarded, and secure. He will then lock the voltmeter box, and give the key to No. 1. No. 4 must, on no account, give up this key until he has seen that everything is safe for the test to be made, and his delivery of the key will be taken as evidence that he has ascertained this to be the case. No. 1 must, on no account, put pressure upon the cable, unless he have this key in his possession, and he must not give up the key until the pressure is off the cable. His so giving it up will be taken as evidence that the pressure is off the cable. No. 4 must stand by the voltmeter box the whole of the time that the pressure is on the cable, and he must prevent any person from touching the box.

(11) This regulation deals with the mode of starting up the apparatus, and putting the pressure on the main; but, as it has no direct bearing on safety to life, it need not be reproduced.

(12) On no account may any alterations in the connections either to the high pressure testing lead, to the earth wire, to the transformers, or to any portion of the apparatus, other than can be effected by moving the switches described above, be made unless the motor is at rest, no matter how often this may involve stopping and starting.

(13) In case of emergency or accident of any kind, the emergency switch controlling the motor and the alternator switch must be pulled off.

This may be done by any person assisting in making the test at his discretion.

After the high pressure test has been made, the insulation resistance of the complete main should be measured. It will probably be substantially

less than that of the original cable, because the joints are included, and they usually lower the resistance materially.

The same insulation tests should be applied to bare copper, but the high pressure test is neither necessary nor safe.

It will be found a great convenience to have a tank capable of accommodating two or three drums of cable in the cable stores, so that cables taken out of the ground or faulty drums may be tested. The portable plant may be employed for the purpose, though in a large station the cost of a permanent testing room for this work would probably be justified.

All tests should be carefully recorded, separate books being used for those made at the maker's works and in the street. Books suitable for this purpose are reproduced. See Forms 1 and 2. The slips shown in Forms 3, 4, and 5 are useful for the rough tests in the street: Form 3 is for the constant; Form 4 for the observations on the cable; and Form 5 for bare strip. All are arranged for five-wire distributors; they can, of course, be easily modified for other systems of mains.

Besides the quantitative tests described, others are necessary during laying. Thus, in connecting up a number of lengths of multiple wire distributors, every separate conductor should be tested, to see that it is rightly connected to the preceding one; if this precaution be neglected, it is by no means a difficult matter to get two conductors interchanged, and, after the whole main is connected up, the mistake may take a long time to rectify. The most convenient apparatus for this testing is a bell and one or two cells.

Another test that may be made with great advantage consists in passing a heavy current through a newly laid main for a few hours. If this be done by means of a battery of a few accumulators, the efficiency of the joints in the main is ascertained; those which are accessible can be felt to find if they are cool, and the presence of bad joints can be detected by measuring the fall of potential in the main, the low voltage under which the current is flowing rendering the test of additional value.

The difficulty has already been pointed out of making tests of mains that have been put into service, except in the case of feeders; every opportunity that presents itself, however, should be taken advantage of. In such tests, it is often impracticable to clean the ends of the cables, and this fact must be borne in mind in judging of the condition of the cables. Feeders should be periodically tested, say, once a week; although the tests may be fairly low, on account of the ends, they will probably not vary greatly from week to week, while an incipient fault will at once be detected.

So far, the tests referred to have been those that are applicable to new mains or those in normal condition; there is, however, another important class, namely, those necessary to discover the position of a fault on a main that has broken down. Such tests are not nearly so simple or straightforward, and their application demands a good deal of ingenuity.

FORM 1.—Cable Testing Book (Manufacturers' Works).

201 **CABLE TESTS AT MANUFACTURERS' WORKS.** 201

Tested at......................................*Works.* *By*..*on*..................................*190*........

To find Constant..

....

....

Constant..*Megohms.*

Manufacturer	No. of Cable	Size	Length	Particulars	Observed Deflection		Shunt	Lead	Actual Deflection		Insulation Resistance in Megohms		Insulation Resistance per mile at 60° F.	Remarks
					After 1 minute	After 2 minutes			After 1 minute	After 2 minutes	Of length	Per mile		

[Blue faint lines continued in this space for additional remarks.]

[Size of opening, *i.e.*, two pages, 13″ by 15½″.] This shows the open folio—two pages facing each other.

FORM 2.—Cable Testing Book (Streets).

151

CABLE

Date....................

1 Cell gives...........*divisions through*
1 Cell gives...........*divisions on Condenser*
Battery gives.........*divisions on Condenser*

Manufacturer.	No. of Cable.	Size.	Color.	Length.	Particulars.	Deflection Observed.		
						After 1 Minute.	After 2 Minutes.	Shunt.

This form is repeated on the same opening of the book.

TESTS.

151

...........*Ohms. Shunt*.............. *Constant*.................*Megohms.*
...........*Shunt* } *Ratio*........... *Constant No.*.........
...........*Shunt* }

Lead.	Deflection Actual.		Insulation Resistance.		Remarks.
	After 1 Minute.	After 2 Minutes.	Of Length.	Per Mile.	
					Position of truck Weather at time of test Section of main Description Cables.—Date laid 190 Date closed in 190 Copper Strip.—Date copper run 190 Supporting bars Test made by

This shows the open folio—two pages facing each other.
[Size of opening, *i.e.*, two pages, $15\frac{1}{4}''$ by $19\frac{1}{2}''$.]

CONSTANT No.......... *CONSTANT*..........................

.... (Perforated here.) ....

(Name of Works here.)

TEST OF MAINS. **CONSTANT.**

CONSTANT No.......... ....190...

POSITION OF TRUCK..

....

....

1 Cell gives.........divs. through 10,000 ohms ....SHUNT

1 Cell gives..............divs. on Condenser.............SHUNT

Whole Battery gives......Divs. on Condenser..........SHUNT

CONSTANT..............................MEGOHMS PER DIVISION

Ratio..................................

Determined by..

Entered Folio.........

[Size $5\frac{1}{4}''$ by $4''$ or thereabouts.]

(Name of Works here.)

TEST OF MAINS. **CABLES.**

CONSTANT No...................... ....190......

WEATHER.. *SIZE*..........................

SECTION OF MAIN...

....

....

DESCRIPTION OF LAYING..

....

DATE LAID.........................190...... *LENGTH*.............*YARDS*

	MAKER	COLOR	DEFLECTION			INSULATION RESISTANCE		REMARKS
			AFTER 1 MINUTE	AFTER 2 MINUTES	SHUNT	OF LENGTH	PER MILE	
+								
⊕								
○								
⊖								
—								

REMARKS—

TESTED BY......................................

ENTERED FOLIO..............

[Size $8\frac{1}{2}''$ by $4\frac{1}{2}''$.]

R

FORM 5.—Slip for Bare Copper.

(Name of Works here.)

TEST OF MAINS. **BARE COPPER.**

CONSTANT No..................... ....*190*.....

WEATHER..........................., *MAKER OF STRIP*..........................

SECTION OF MAIN..

....

....

DESCRIPTION..

.... *SIZE*.....................

DATE CLOSED IN...........................*190*...... *LENGTH*...............*YARDS*

DATE COPPER RUN...............*190*...... *SUPPORTING BARS*..............

	DEFLECTION			INSULATION RESISTANCE				REMARKS
				OF LENGTH		PER MILE		
	+TO LINE	−TO LINE	SHUNT	+TO LINE	−TO LINE	+TO LINE	−TO LINE	
+								
⊕								
O								
⊖								
−								

REMARKS:—

TESTED BY..

ENTERED FOLIO..............

[Size 8½″ by 4½″.]

Faults may be divided broadly, according to their mode of occurrence, into two classes, namely, (1) those occurring on a single main of uniform sectional area without branches; and (2) those occurring on a network or on a main of variable section or having branches. They may further be divided,

according to their nature, into (1) 'earths,' or the failure of insulation of one conductor; and (2) 'shorts,' or the failure of insulation of two or more conductors of different polarity, causing the conductors to be in contact with one another, either directly, or through the intervention of some conductor at earth potential. Both classes of fault may develop into an 'open circuit,' the earth usually by slow corrosion, the short by fusion of the conductors.

Before considering the methods of locating faults, a few general observations may be made. The precise point at which low insulation becomes an earth depends largely on the pressure of supply; that which would be fairly satisfactory insulation for low pressure work would be a dead earth for high pressure. The same remark applies to shorts; there is no halting place between practically perfect insulation and a dead short with high pressure, while with low pressure an almost insignificant resistance will prevent a really excessive current.

It is interesting to notice the behaviour of the different kinds of main when faulty.

In the case of cables in pipes, an earth on one conductor, if not quickly removed, will almost certainly develop into a short; on the other hand, although all the cables may be melted, and there may be a seething mass of molten copper in a cast iron pipe, it may yet be possible to continue running, and, in many cases, the fault may be burnt out into an open circuit and the short be thus got rid of.

The explanation of this remarkable behaviour is, probably, that the conductors are never actually in contact with one another, an arc, sufficient to admit of a considerable difference of potential, being maintained between them; there is, in fact, an electric furnace set up in which the conductors are the electrodes. The action is favoured by the rigidity of the cables which are held apart by the dielectric some feet away from the arc, the insulating covering usually remaining comparatively cool, which is an additional proof that the copper is melted by the heat of the arc and not by the heat generated by the resistance of the copper. It is possible, also, that in some cases the heavy currents flowing in the conductors may by their electro-magnetic action tend to separate them.

While the arc is maintained, destructive distillation of the dielectric and of the tar in the compound on the outer wrappings is going on, with the result that the interior of the pipe in the vicinity of the fault rapidly becomes filled with gases that will not support combustion, so that the dielectric ceases to burn and the arc is in time extinguished.

It may be noted in passing that these gases, produced by distillation, flow on to other parts of the pipes and form an explosive mixture with the air, frequently igniting and developing sufficient pressure to lift the flag-stones above.

Vulcanised bitumen covered cables possess the important advantage that

they will not act as a torch, *i.e.*, the fire does not run along them as along rubber.

When cables are laid on the solid system, an earth is not so certain to produce a short, though it is very liable to do so. When this occurs, the bitumen around the faulty cables is usually completely burnt, and, if a wooden trough be employed, this is reduced to charcoal. The resultant gases frequently escape through cracks in the ground, sometimes with such force as to resemble an escape of ordinary gas from a pipe. With this system, there is no danger of explosion, and there is a somewhat better chance of the arc being stifled. With vulcanised bitumen cables, it is remarkable to how small a length of main the damage by heat is confined, usually only a very few feet.

When lead-covered cables are used, an earth is likely to be much more serious than with the other class, because, the lead being a conductor, the damage may extend hundreds of yards away from the original seat of the mischief, and, owing to its fusibility, a great length of main may be destroyed.

Bare copper systems behave very differently. An earth on one conductor has little, if any, tendency to produce a short circuit, but, on the other hand, there is greater risk of short circuit from other causes. The most likely causes of short circuit on bare strip, apart from accidental damage by the operations of workmen in the neighbourhood, which risk is common to all systems, are rats and abnormally heavy currents. Rats may run along the culvert and knock the strips into contact; heavy currents may cause them to swing by reason of electro-magnetic attractions and repulsions; and, in any case, the heavy current flowing during the first momentary contact may set up violent swingings of the strips, which will then become welded together.

One extraordinary instance of a combination of the two causes named is worthy of record. A large rat got across a pair of $\frac{1}{4}$-square-inch conductors, and its resistance was sufficiently low to allow a heavy current to flow; neither these conductors nor those in many other culverts between the point and the station stirred, but it so happened that close to the station, about a mile and a half away, there was a culvert in which each conductor was composed of two $\frac{1}{8}$-inch strips instead of one $\frac{1}{4}$-inch strip; these swung so violently that they came into contact and were welded together.

When a short circuit does occur on copper strip, it is totally different to one on cables. The area of contact is usually very large, the arcing is comparatively insignificant, and there is nothing tending to extinguish it. The result is that it is practically impossible to burn out such a fault.

In the case of high pressure mains, when a short takes place, burning out does not usually occur in the first instance, because such mains are almost invariably protected with fuses. If the main be a concentric one, such as is usually employed for high pressure, it will be found that the path of the current is shown by a fine blackened hole through the dielectric,

perhaps not larger than a needle will just pass through, and if the insulation resistance be measured with a battery, it will probably be found to be high. Such high resistance faults are exceedingly difficult to find, and it is therefore usual to put in heavy fuses and burn the fault into as low resistance a one as possible.

Returning to the testing of faults, it is usually an earth that is tested for, a short or open circuit being by its very nature usually self-revealed; the former by a local disturbance, the latter by cessation of supply.

It is not possible to enter here into details of the various methods employed to localise an earth. Speaking generally, a single main of uniform section, without branches, presents little or no difficulty, whether the fault be an earth or a short, and whether the main be single or concentric.

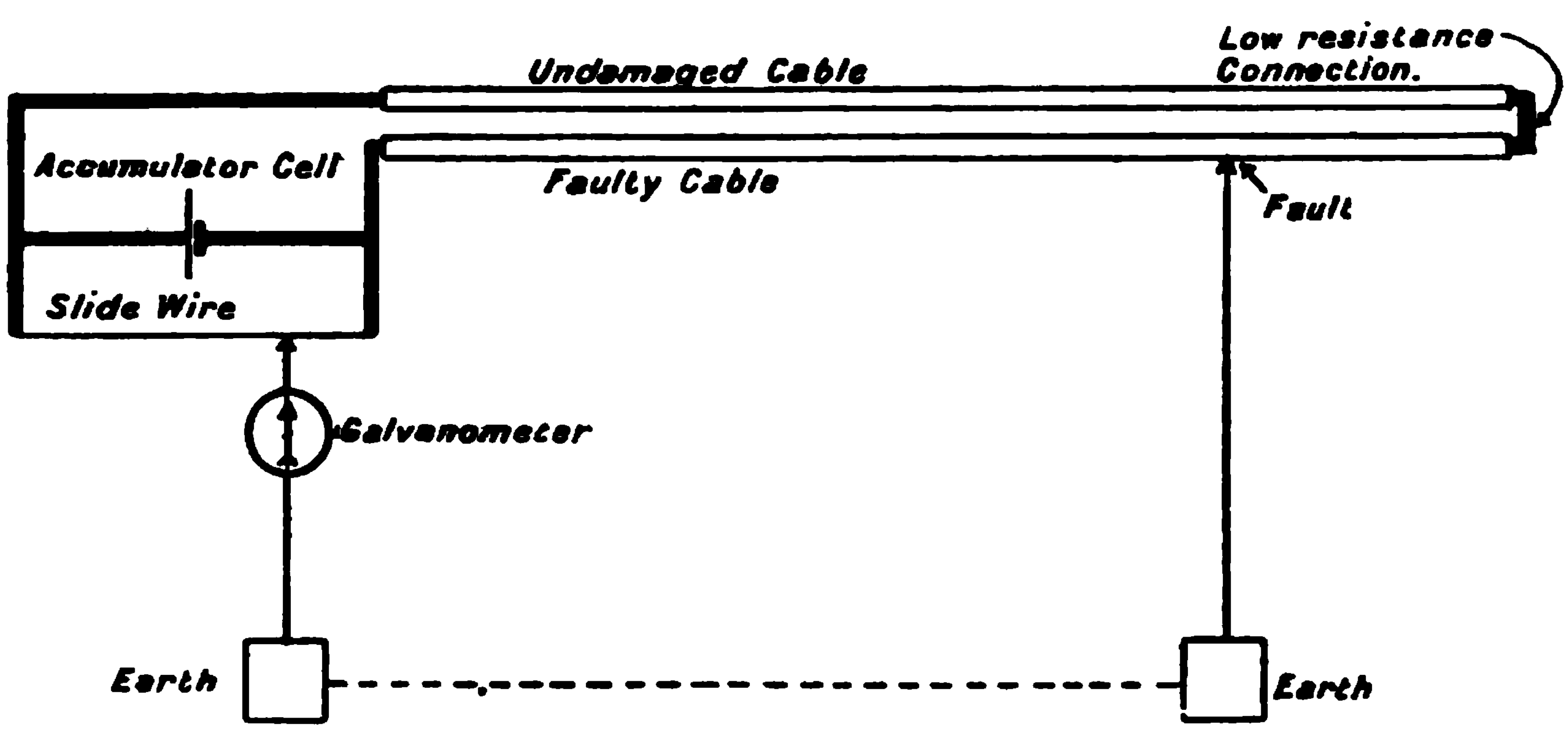


FIG. 95.

One of the most useful tests for such a main is the loop test. This requires a second conductor, which, however, is usually available. To make the test, a considerable current, usually derived from one or two storage cells, is passed through the faulty cable and through another cable running along the same route, the far ends of the two cables being connected together. Across the ends of the same battery is connected a slide wire, to the moving contact of which is attached one end of the high resistance coil of a galvanometer, the other being connected to earth. There is thus formed a Wheatstone bridge, of which the two portions of the slide wire form one pair of arms, the faulty cable up to the fault and the remainder of that cable, *plus* the second cable, forming the other pair; the galvanometer circuit being completed through the earth and the fault. When balance is obtained, the position of the fault can easily be calculated, if both mains be of the same sectional area, or the cross-section and length of each be known. Fig. 95 will make the connections clear.

The chief advantages of this method are, that it is independent of the

actual resistance of the main, and that it is unaffected by the resistance of the fault, a high resistance merely reducing the sensibility of the galvanometer. It is capable of giving very close approximations to the position of the defect, the Author having known faults localised to within a few yards in several miles.

The accuracy of the test necessarily depends, among other things, upon the degree of fineness of adjustment of the slider, which obviously varies with the length of the slide wire. For a long main, a number of wires are necessary; a very convenient form, devised by the Author for the London Electric Supply Corporation, and since copied by Messrs Elliott Bros., consists of a single wire passed round a series of pulleys, so as to form ten

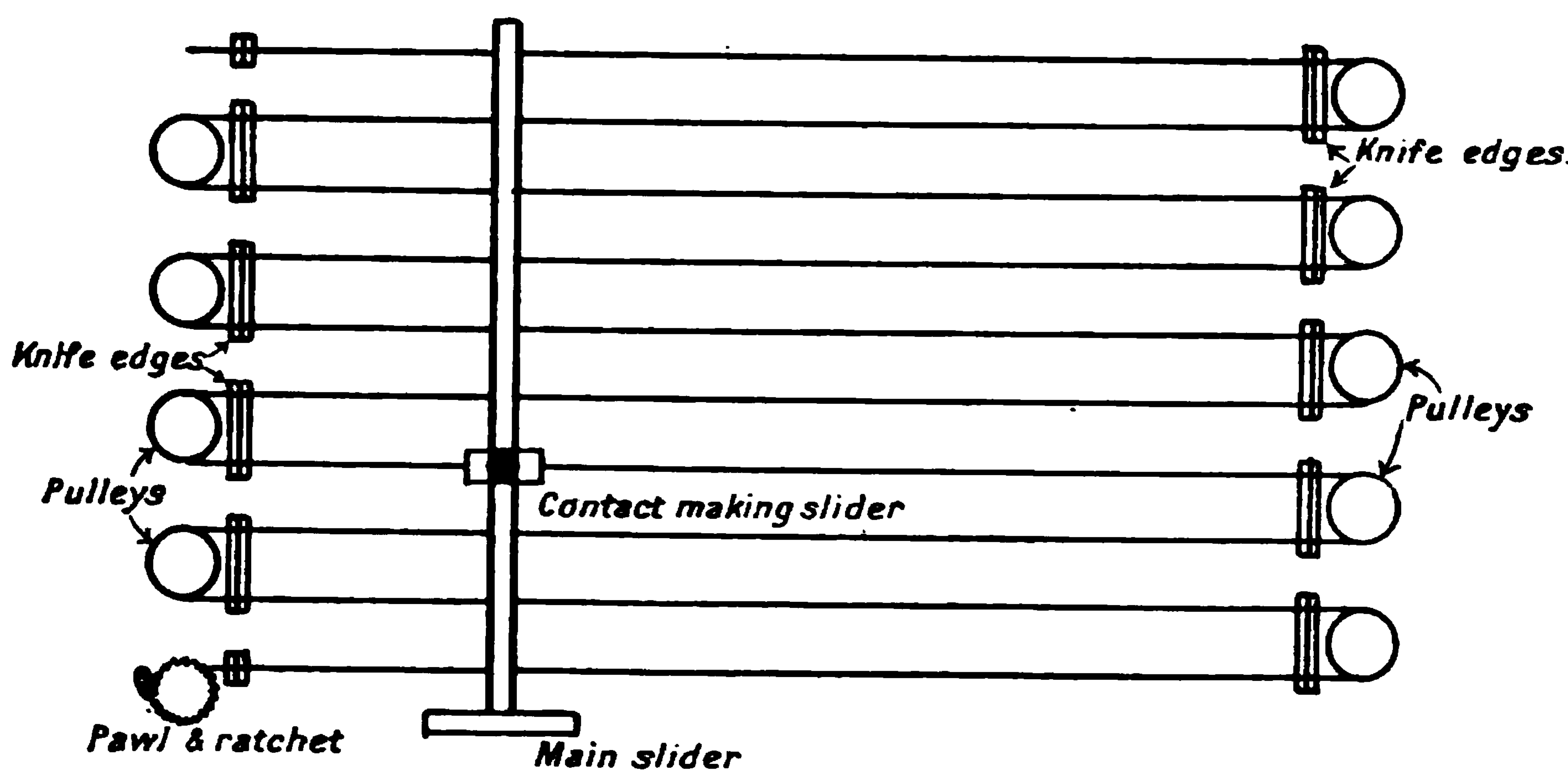


FIG. 96.

parallel sections; a number of knife-edges clamped on to the wires serve to exactly determine the length of wire in use. The slider has two motions at right angles to one another, so that it may pass from one section to the next. The arrangement is shown diagrammatically in fig. 96. The object of using a single wire passed round pulleys is to secure uniform tension, and therefore equal resistance, in all the ten wires. Until this device was resorted to, it was found very difficult to obtain equality.

There are numerous other ways of testing based upon the loop test into which it is not necessary to enter here. They differ merely in the way of carrying it out.

Another method frequently used consists in passing an alternating or intermittent current through the fault, and carrying a large coil, in the circuit of which is included a telephone, along the route over the main, the sound ceasing or diminishing when the fault is passed. In some cases, this

gives accurate results, but it is often misleading, owing to leakage currents passing down such conductors as gas and water pipes.

Sometimes a steady current of considerable magnitude is passed through the fault, as in the last method, and a compass needle substituted for the telephone and coil.

Other methods depend on the use of a differential galvanometer, the instrument showing the difference in the current carried by the two conductors constituting the feeder, which difference is equal to the leakage current. This test, which is only applicable to continuous current systems, can be made without interrupting the supply.

The case considered is only met with in feeders. In a distributing main, the problem is complicated by the service lines, the loop test obviously merely showing that the fault is a certain number of microhms away, and not discriminating between the thick, low resistance, distributor, and the thin, comparatively high resistance service.

In the case of a large single network, the difficulties are so enormously magnified that in the Author's experience any attempt at testing, in the usual acceptation of the word, is out of the question. A little consideration will show why this should be so. In the first place, any method depending on the measurement or comparison of the resistance of the conductors cannot give any determinate result, because there are several or many paths to the fault. Again, methods based upon the presence of an excess current on one side of the system must fail, because this excess current may travel through many different paths. Methods depending on an interrupted, alternating, or unusual periodicity current, either alone, or superposed on the ordinary current, are liable to failure for the same reason, and also because of the many opportunities the leakage current has of returning to the station.

The Author's experience has shown him that, for faults of the kind referred to, there is nothing so rapid or certain as the unscientific and brutal method of trial and error comprised in dividing the network bit by bit until the faulty length is localised.

Suppose an earth develops on a large single network supplied from a number of low-tension feeders, how is it to be found? First of all, entirely disconnect each feeder in turn, momentarily connecting a different pole of the network from that on which the fault is to earth, through a fuse and ammeter, and noting the deflection, or, if the earth be a bad one, seeing whether the fuse goes. If the fault be on a feeder, it will be at once ascertained on which it is by the earth disappearing when the particular feeder is disconnected, and it can then be localised by the loop or other convenient test. If the defect be found to be on the network, this is then divided into two approximately equal parts, supplied from two separate sets of plant. The necessity for the apparatus described in Chapter XXI. for disconnecting mains with the current flowing now becomes evident. The

FORM 2.—Cable Testing Book (Streets).

151 **CABLE** **TESTS.** 151

Date....................

1 Cell gives...........*divisions through*
1 Cell gives...........*divisions on Condenser*
Battery gives........*divisions on Condenser*

...........*Ohms. Shunt*..............
...........*Shunt* } *Ratio*...........
...........*Shunt* }

Constant.................*Megohms.*
Constant No..........

Manufacturer.	No. of Cable.	Size.	Color.	Length.	Particulars.	Deflection Observed.		
						After 1 Minute.	After 2 Minutes.	Shunt.

Lead.	Deflection Actual.		Insulation Resistance.		Remarks.
	After 1 Minute.	After 2 Minutes.	Of Length.	Per Mile.	
					Position of truck Weather at time of test Section of main Description Cables.—Date laid 190 Date closed in 190 Copper Strip.—Date copper run 190 Supporting bars Test made by

This form is repeated on the same opening of the book.

This shows the open folio—two pages facing each other.
[Size of opening, *i.e.*, two pages, 15¼" by 19½".]

CONSTANT No......... *CONSTANT..........................*

.... (Perforated here.) ....

(Name of Works here.)

TEST OF MAINS. CONSTANT.

CONSTANT No......... ....*190...*

POSITION OF TRUCK...

....

....

1 Cell gives.........divs. through 10,000 ohms ....SHUNT

1 Cell gives..............divs. on Condenser.............SHUNT

Whole Battery gives......Divs. on Condenser..........SHUNT

CONSTANT..............................MEGOHMS PER DIVISION

Ratio..................................

Determined by..

Entered Folio.........

[Size 5¼" by 4" or thereabouts.]

(Name of Works here.)

TEST OF MAINS. CABLES.

CONSTANT No...................... ....*190.....*

WEATHER.. *SIZE..........................*

SECTION OF MAIN..

....

....

DESCRIPTION OF LAYING...

....

DATE LAID..........................190..... *LENGTH.............YARDS*

	MAKER	COLOR	DEFLECTION			INSULATION RESISTANCE		REMARKS
			AFTER 1 MINUTE	AFTER 2 MINUTES	SHUNT	OF LENGTH	PER MILE	
+								
⊕								
○								
⊖								
−								

REMARKS—

TESTED BY.......................................

ENTERED FOLIO..............

[Size 8½" by 4½".]

The particulars as to the depth of the main and its distance from the buildings must be taken while it is being laid and before the ground is closed in, and the opportunity can also be taken of verifying the position of existing gas, water, and other pipes.

The way in which the various details are recorded is as follows: As will be explained subsequently (see Chapter XL.), all work done by the Mains staff is carried out to written instructions or Works Orders, and each job has its own Works Order number. The first step in making the record is to prepare a tracing, or, if the work cover a very large area, a series of tracings. These tracings show the street along which the main is to be laid, and so much of the side streets as is necessary to indicate where they branch off, but no more; no existing underground works are shown. The tracings are made from the 10 feet to the mile Ordnance maps (more accurately 1 inch to 41·66 feet), which are prepared from the latest survey, and are to the largest scale of any published; these maps are kept absolutely up to date by the drawing office staff, who correct them so as to show all alterations made from time to time in the course of street improvements and otherwise. A single tracing usually requires several sheets of maps to build it up.

Fig. 97.—Mode of recording position of cable main.

Having prepared the tracing in black ink showing the street as it exists, the new work is laid down in blue ink. Cables laid on the solid system and in pipes are shown in each case by their centre line, while culverts are indicated by two lines drawn approximately to scale according to the width of the culvert. In all cases the lines are plotted in their correct position, the map being sufficiently large to admit of this being done with very fair accuracy.

Wherever a change in direction, whether vertically or horizontally, takes place, the distance from the building line to the centre, and the depth from the surface of the flags to the top of the pipe or culvert, is figured in blue ink within the building line, an arrow indicating the point to which the figures refer. The distance out is written first and the depth second. Fig. 97 shows the way the record is made.

Beneath the centre line is written the type and size of main, as, for instance, '$5 \times \frac{1}{2}$ square inch in bitumen,' or '$3 \times \frac{1}{4}$ square inch in pipe.' If the main be a culvert, the description of culvert, as five-way, seven-way, the number of conductors being shown afterwards when they are actually drawn in, as all the ways may not bo used in the first instance. The positions of the straining bars and supporting bars are all plotted in their correct positions, being indicated by a short transverse line, and, in addition,

the distances between them are figured, the position of the straining bar being shown by a measurement from some such landmark as the corner of a building (see fig. 98).

Manholes are shown by an open circle, the size of which bears no reference to that of the box, while so-called 'dummy' holes, *i.e.*, small brick joint boxes made on pipe lines for service joints, are indicated by small circles filled in solid. The details of manholes are recorded in a manner to be explained later.

When a manhole contains disconnecting apparatus, as do those at all points of intersection in the Author's practice, the letters P.D. are written opposite the open circle, these letters being an abbreviation of pillar distributor, the name of the apparatus used (see Chapter XXI.).

Joints on main conductors connecting different lengths together, as distinguished from service joints, are shown by a short transverse line against which is written 'Joint on +' 'Joint on – ' etc. If a box is used, 'Joint box' is written instead of 'Joint.'

FIG. 98.—Mode of recording position of culvert.

At various points a section of the main is shown on the tracing, the point at which it is taken being indicated by a line identified by letters, and the sections being shown on a convenient part of the tracing away from the street. The drum numbers of the cables are written against them in the sections, so that any particular length supplied by a manufacturer can be identified.

In the case of culverts, a series of longitudinal sections are made, giving the fall, the bottom of the culvert being shown above a datum line, which is usually taken 5 feet below the highest point. On the section is written the inclination of the culvert, the minimum allowed in the Author's practice being 1 in 150, and a note is made on the section of the date the culvert was completed and the ground filled in.

A note of the insulation resistance of each length of conductor, measured before it is jointed up to adjoining lengths, is written against the line or lines showing the route, and, in the case of cables, the factory number and number of the drum on which the cable was supplied are added for purposes of complete identification.

Along a line parallel to the main is written the date that each length of

flagging was booked into the Highway Authority as being ready for re-instatement.

As already stated, each Works Order has its own distinct tracing or set of tracings. The tracing has the Works Order number written in the top right-hand corner. On the top of the tracing is written a complete summary of the work done under the Works Order, *i.e.*, the number of yards of culvert, specifying the number of ways and the date of completion of each section, together with the size of the copper strip conductors and the dates they were run, each section of culvert on a given Works Order being numbered for reference. The total length of each size of cable laid, the date of laying, and the name of the maker, is also shown, and the number of pillar distributors and the date of their being fixed. If the main replaces an old one, particulars are shown in the summary in a similar manner of all material taken up and returned into the stores, while any material issued in excess of the requirements and subsequently returned is also entered.

So far, feeders and distributors only have been referred to; for service mains a small separate tracing is made for each one laid. This is traced from the same maps as the others, and just enough of the plan is shown to identify the position of the building. The distributing main is shown, and the service is indicated in its proper position by a line from the main into the building, the size, number of conductors, and the name of the maker of the cable being written against it. The exact position of the joint is shown by figuring the length measured along the distributing main from some clearly defined point on the Ordnance map, such as the corner of a building. In the top right-hand corner is written the consumer's Works Order number and in another the quantity of cable used and the date laid.

In order to make the above descriptions clear, a typical tracing relating to distributing mains is shown in fig. 99, and one dealing with a service in fig. 100.

It will be apparent that the number of tracings in a system of even moderate size is very great, and, since any one may have to be referred to, it is of the utmost importance that they should be clearly and conveniently indexed.

The small tracings, *i.e.*, those relating to services and very small extensions of distributors, are kept in guard books, being so folded that they can be easily opened out; they are pasted along one edge, and some seven or eight of these will be contained on one page of the book. Since each contains 150 pages, each book contains over a thousand tracings. The tracings are pasted in in the order of date of completion of the work they relate to.

An index is provided for each guard book, in which columns are provided for the name of the street, the township or district, the date the work was done, the description of the work (sufficient to identify it), and its Works Order number, and, finally, for the page in the book on which the tracing is. In using the index, the Works Order number and date of execution are very helpful in finding the tracing.

The large tracings are indexed in a precisely similar manner, a distinct index book being provided, but, in place of being pasted in guard books, they are rolled up and marked on the outside with the name of the street and the Works Order number, and each is given a consecutive number as

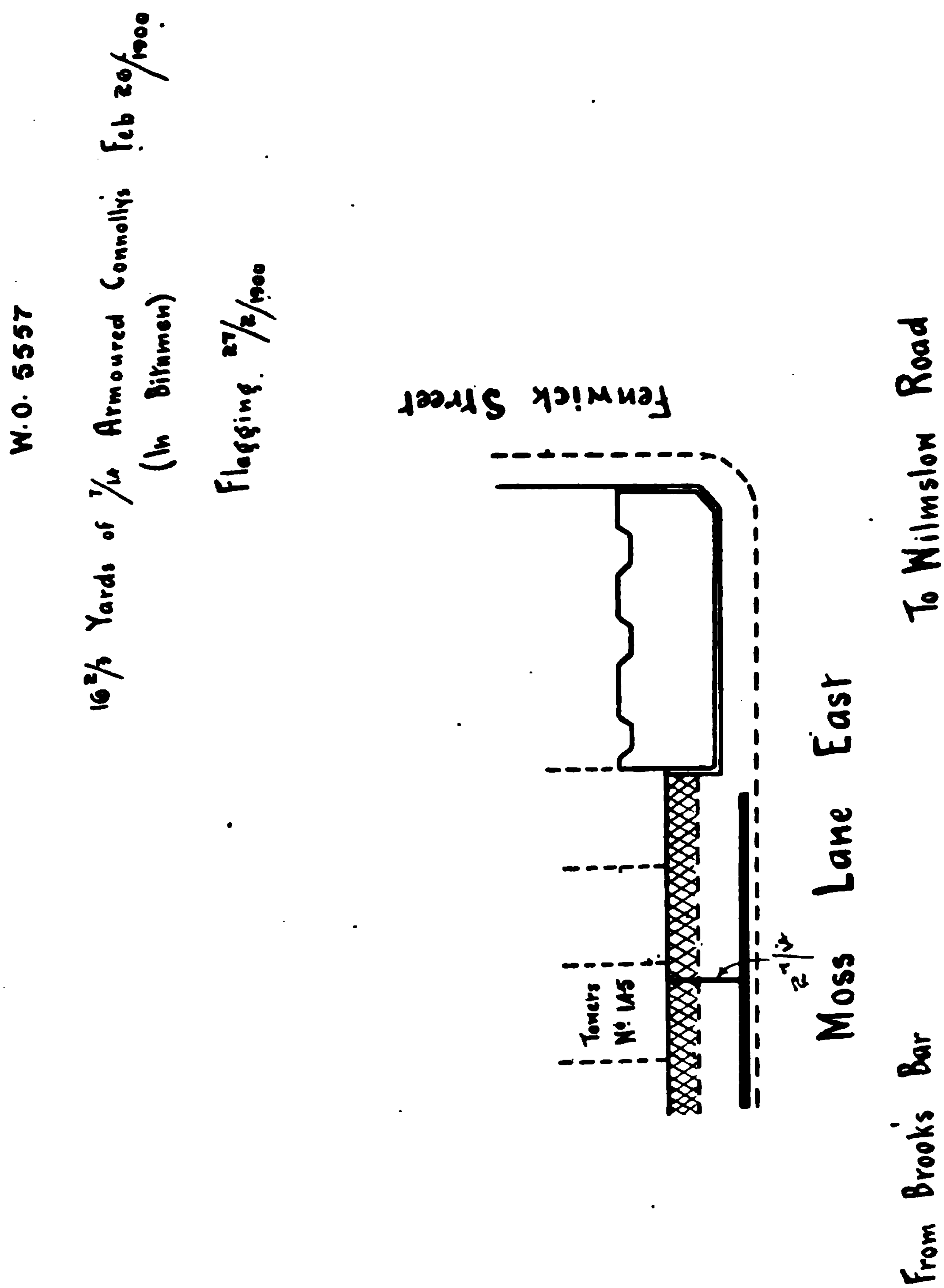


FIG. 100.—Service Main tracing.

though it were a page in a book. The tracings are put away in drawers, each holding a hundred, and these drawers are numbered 1–100, 101–200, etc.

The records described so far are complete, and show absolutely everything it is possible to know about the main at the time it is laid, and, so far as the

work authorised by a given Works Order is concerned, nothing m needed. It is, however, apparent that if subsequently further wo carried out in the same street, as, for instance, if a main be laid on the side of the road, or if services be attached to the original main (as w course, be the case), the original tracing will cease to accurately represen main, unless the new work be entered on it; and, if this be done, original record will be interfered with and its value destroyed, since it then cease to represent the original Works Order to which it related.

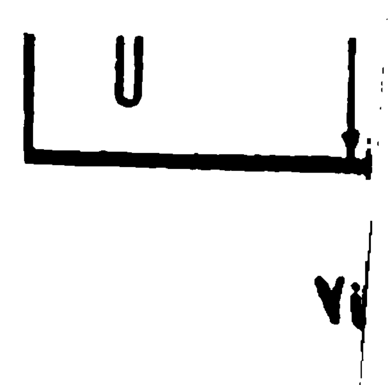
In order to meet this difficulty, a second set of plans is prepared, s what less detailed, but still very complete. For this purpose, the orig Ordnance maps themselves are used, and on them is plotted the result of carrying out of all Works Orders relating to the area in question. T show the actual state of the mains at the time, every new main being plo on them, and old mains that may have been taken up being erased. maps themselves are also corrected so as to show all new buildings, st improvements, tram lines, etc. The plans thus show at a glance all feed distributors with their branches, services, junction boxes, etc., as they e up to date; while the tracings, which are never altered, show the work do at the successive periods which has resulted in the existing state of things.

Turning now to the way in which these final records are made, the 1 feet to the mile Ordnance maps for the whole district are mounted on brown holland, and are well bound, in batches of 30, in very strong books, without being folded, the books opening out flat, with a map to each page.

A key plan to the whole district, consisting of the 6 inches to the mile Ordnance map, is provided, and this is divided into sections, each corresponding to 30 of the large maps. The sections are numbered consecutively, and each of these numbers corresponds to a book containing 30 maps. At the beginning of each book is placed a key to the 30 maps it contains, consisting, like the principal key, of a portion of the 6-inch Ordnance map. The individual maps in each book are numbered from 1 to 30, their numbers being shown on the small key. Each map is marked on its four edges with the identifying numbers of the maps adjoining those edges, each map having two numbers, that of its number in its book being placed first, and that of the book second. Thus, in fig. 101, a map is shown which is, say, No. 20 in book 3. This is numbered in the top right-hand corner. On the north is number 10 in the same book, shown by the figure 10, the number of the book being omitted, because it is the same as the one in which the map in question is bound. On the west is number 19 in the same book, *i.e.*, 19. On the south is number 10 in, say, book 6, shown thus 10–6; while on the east is, say, map 11 in book 4, shown 11–4.

This indexing of the maps has been described in detail, because it is important to have them in a convenient form for ready reference.

All kinds of mains, except culverts, are shown on these maps by a single


U

ew from B.C.

[To face p. 271.

line, corresponding in position to their centre lines, distributing mains being shown red and feeders blue. Culverts are shown by two lines to scale, as on the tracings, those containing distributors only being red, those feeders only blue, while those containing both are distinguished by a blue line just outside the red lines. No straining or supporting bars are shown for culverts, nor joints on mains for other systems, except at those points at which the main changes in size; but manholes are indicated by open circles in red, and 'dummy' boxes by filled-in smaller circles.

The date at which each section of main was laid is shown against it to facilitate reference to the tracings, and the description of the main, together with the number and size of the conductors constituting it, are written in. All dimensions relating to the depth and distance out are not shown, but only the salient ones, the distance out from the buildings being written in red figures, and the depth in blue.

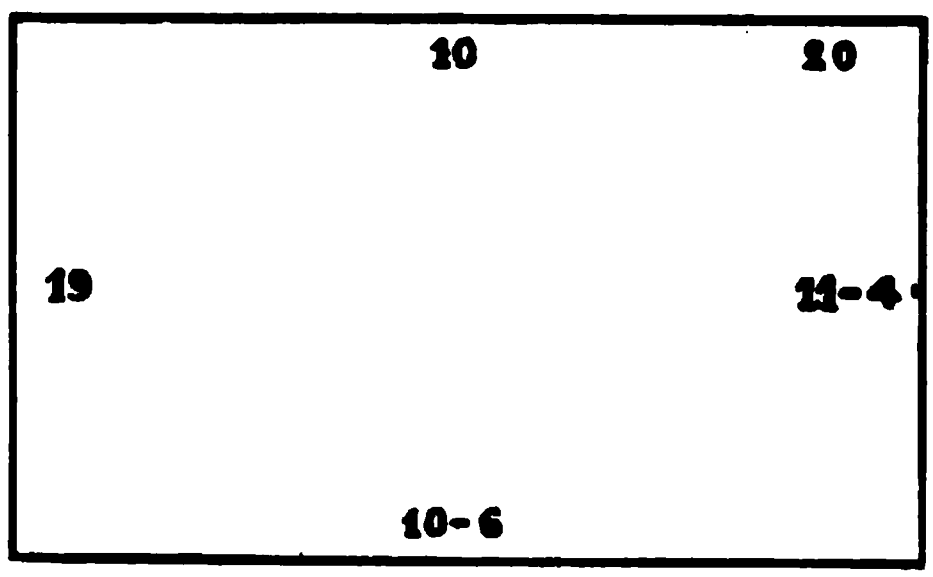


FIG. 101.—Identifying numbers for map.

As already stated, the manholes are merely indicated on the tracings and plans by circles. Each one is numbered, and a tracing corresponding to the number is prepared and pasted in the 'Junction Box Reference Book.' The tracing shows a plan and two sectional elevations of the box and the apparatus therein, with size of cables and similar particulars. A sample tracing is shown in fig. 102.

All manholes are periodically inspected, and the inspectors make out a daily report of their work on the form reproduced in Form 6. From this form the date of inspection and condition of each box are entered up in the Reference Book, so that full particulars of each manhole can be seen at a glance.

The Pillar Distributors are numbered independently of the manholes in which they are fixed; the necessity for this will be apparent later on.

The recording of the distribution of the consumers, with particulars of their demand and the balancing of their load, is the next matter to be considered. This requires a very careful arrangement to enable the actual state of things to be readily seen and appreciated in all its bearings. Not

FORM 6.—Junction Box Report.

(Name of Works here.)

..............................190...

DAILY REPORT.

JUNCTION BOXES.

No.	WHERE SITUATED.	CONDITION.	DRAIN.	REMARKS.	Date Attended to.

....

Mains Foreman.

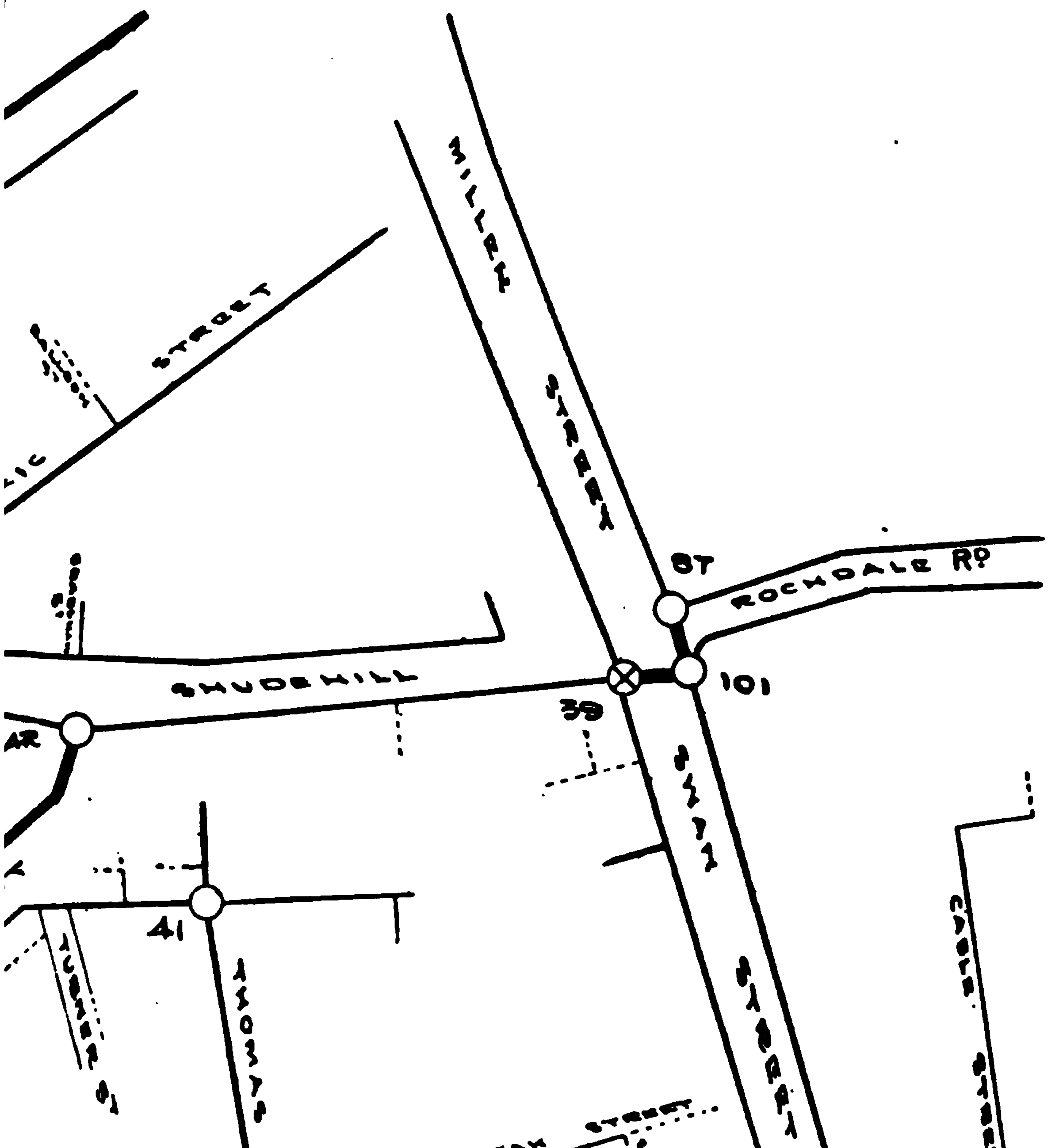
Date returned..............190

[Size 8¾" by 11".]

only is this necessary to show the existing load on the distributors, but also to show to which mains new services should be attached.

It is obvious that a consumer's list in which they are grouped alphabetically, or even according to the streets, is of no use whatever, as portions of a street may be on different mains; and, on the other hand, a single main may traverse several streets. Clearly, then, the consumers must be arranged according to the mains from which their installations are supplied.

The first step is to prepare a diagram of the distributing network; no streets or houses are shown, but each main is shown by a single line drawn so as to represent as nearly as possible the length and position of the main in its relative position to the other mains. The diagram is thus roughly to scale, and the lines form a kind of skeleton map. Where mains are laid on both sides of the street, two lines are shown, and, for the sake of clearness, they have to be drawn further apart than they should be, if to scale, but this is of no consequence.



MILLER STREET
ROCKDALE RD
87
101
39
SHUDEHILL
41
THOMAS
TURNER ST
SWAN STREET
81
CABLE STREET
OAK STREET

[To face p. 273.

The size of main is reckoned by that of one outer conductor, and the thickness of the line indicates the sectional area of the conductor; probably there will not be more than three or four sizes in use.

The points of intersection will all be provided with disconnection devices, Pillar Distributors being used by the Author, as already mentioned, and these are shown by circles. If a feeder enters the network at one of these points, it is indicated by a cross placed within the circle, the course of the feeder from the station not being shown, as it does not affect the matter in hand. Each pillar has a number given it for identification on the diagram, hence the necessity for their numbers differing from those of the manholes.

The Author has found that the only practical way of balancing a network satisfactorily is to balance its component parts, and to let the total balancing take care of itself. The sections taken for this purpose are those into which the network is divided by the pillars.

A series of sheets are prepared, one sheet (or more, if necessary) for each section, and each is headed with the numbers of the pillars forming its extremities. Then follows the name of the street in which the first pillar is fixed, and the numbers of the houses in it occupied by consumers, written in their order, reckoning from the pillar.

If the section of main is laid in several streets, the names of the streets and the numbers of the houses in them follow in order until the pillar at the other extremity of the section is reached.

On the right hand side of the page are ruled vertical lines, corresponding in number to the conductors forming the distributors, usually three; five if the system be a five-wire one. At the top of each line is written the symbol representing the polarity, and also the size of the conductor, ½ square inch, ¼ square inch, or whatever it may be. The current taken by the consumer's installation at the pressure existing between the mains to which his service is connected is then written between the lines corresponding to those mains.

By this means the exact distribution of the load on the main is seen at a glance, and by adding up the columns formed by the lines representing the mains, the total amount of the demand is obtained.

If the main have branches leading into side streets, which streets are not connected at their far ends to other mains, the total balancing in this branch is found and written on the sheet, showing the main section in its proper position, *i.e.*, between the two numbers in the main street that belong to the houses at the corners of the branch street, this being indicated thus, 'Here is . . . . Street.' The actual balancing of the side streets is shown separately on the same sheet, or on one attached to it.

A reference to pp. 228–230 will make this description clear, it being remembered that in the actual sheets the list would be headed with the numbers of the pillars, and instead of 'branch main' the name of the street

would be given, while the names of the consumers instead of their occupations would be entered. A portion of the diagram of the Manchester network, with pillars marked in, is shown in fig. 103.

If a section is ultimately divided into two, by the fixing of an intermediate pillar, necessitated by additional branches forming a new point of intersection, fresh sets of sheets are made out for each of the two portions into which it is thus divided.

Owing to the frequent changes made by the constant accession of new consumers, it is practically impossible to arrange to print any of the sheets; hence they have to be rewritten at frequent intervals, but this is an exceedingly simple matter, involving little trouble.

The diagram of the network thus forms a key to the sheets; these are contained in files or portfolios, and are arranged in groups 1–10, 11–20, etc., a given section of main being put in the group corresponding to the pillar having the lower number of the two forming its ends.

In order to see how the sheets are used, suppose that a consumer has to be connected in a given street. The exact situation of his premises is first found with the help of a directory and an ordinary map, the large wall map of the whole district being the most convenient. This point is then located on the diagram, when it is at once seen between which two pillars it is situated. The street corresponding to these two is then looked up in the portfolio, and the exact state of the balancing on the particular main is seen at a glance. It can then be decided, without any difficulty, which pair of mains the new consumer is to be supplied from.

It may be as well to point out that all that can be attempted is a 'paper' balance, *i.e.*, the balancing of the load as it would be if all consuming devices were at work. Clearly, such a state of things may never be realised. In the absence, then, of any knowledge of the actual balance at any one time, the above method is the best that can be adopted, if care be taken to put, as far as possible, similar consumers on opposite pairs of mains. A very near approach to accuracy, under working conditions, may be attained, and the balancers must make up for the rest.

In addition to the balancing sheets proper, it is very convenient to have a consumer's list for reference, in which the streets are arranged alphabetically and the consumers' loads shown in columns, provided by means of lines representing the mains, as in the balancing sheets. This list may conveniently be printed, new consumers' names and their loads being written in, and a new set printed, say, once every three months. For a station of moderate size, a single sheet framed is very convenient; for a large station, a number of sheets must be used.

CHAPTER XXV.

METERS AND APPLIANCES ON CONSUMER'S PREMISES.

In all cases of public supply, it is necessary to measure the total amount of energy supplied to individual consumers, and, with some systems of charging, it is equally important to measure the maximum rate at which it is delivered. The word 'meter' is usually confined to instruments for making the former measurement, those for the latter being referred to as 'maximum recorders' or 'demand indicators.'

To each of the two fundamentally different systems of distribution, *i.e.*, by continuous and by alternating currents, belong certain classes of meter that will only work with a particular kind of current, while some are common to both systems; these last are usually dependent for their action on the square of the current.

The measurement of continuous current is far easier than that of alternating, because, in the latter case, the power is only equal to the product of the pressure and current if the circuit be free from self-induction, and this point alone is a strong argument in favour of continuous current distribution. In what follows, it is assumed that in the case of alternating currents the circuit is non-inductive.

Since all distribution is effected at constant pressure, it is sufficient to integrate the current only, and to multiply the result by the pressure, provided, of course, that the standard pressure is closely maintained. This course is adopted in a large number of meters, and is quite satisfactory in practice. If, however, greater accuracy be desired, the principle of the Watt-meter must be employed. Here the stress between two coils, one of which carries the main current and the other a shunt current proportional to the pressure, is made use of.

Meters fall broadly into four classes:—

(1) Those in which the current to be measured, besides controlling the registering gear, supplies the motive power for it.

(2) Those in which the current to be measured controls the registering mechanism, while a separate current supplies the motive power.

(3) Those in which the current merely controls the mechanism which is

driven by some force altogether external to the current, such as a spring or weight.

(4) Those in which no gearing is driven, but chemical action goes on, involving an alteration in mass of a plate of metal or of a liquid.

(1) The best known, and most widely used, meters of this class are the Ferranti and Chamberlain & Hookham meter for continuous currents, and the Chamberlain & Hookham and Shallenberger for alternating, together with the Elihu Thomson, which is available for either kind of current without alteration.

The Ferranti meter depends for its action on the fact that when a mass of mercury is cut normally by lines of magnetic induction, and an electric current flows radially through it, the mercury tends to rotate. If the same current that flows through the mercury excites the field, the speed of rotation will be proportional to the square of the current; but, mercury being a fluid, its motion is opposed by friction against the sides of the containing vessel with a force that varies as the square of the speed, hence the speed of rotation is proportional to the current. This principle, though equally applicable to the measurement of continuous and alternating currents, has been chiefly developed in connection with the former.

When the principle is applied to making a practical instrument, an aluminium fan, mounted on a spindle, is immersed in the mercury and is carried round by it. The spindle carries a pinion gearing into a train of counting wheels, the gearing being so made that wheels having different numbers of teeth can be inserted so as to allow for variations between individual meters and render them direct reading in Board of Trade units.

The counting mechanism introduces friction that is practically independent of the speed of rotation, and is greater when the meter is at rest than when it begins to move. The whole friction is thus made up of two parts, one varying as the square of the speed, the other independent of the speed; obviously, the relative importance of the latter diminishes as the current, and therefore the speed, increases.

In order to compensate for the error that would thus be introduced, a permanent magnet is employed to give a certain field independently of the main current. The relative importance of this initial field manifestly decreases as that due to the main current increases, and hence it is found possible to practically compensate for the friction of the train. Adjustments of speed are made by roughening the interior surface of the bath containing the mercury, and so increasing the fluid friction.

Inasmuch as the permanent magnet is remagnetised every time the maximum current passes through the meter, there is no danger of its falling off in strength with lapse of time; but if, on the other hand, a current in excess of the maximum for which the meter is intended be passed through its

coils, the permanent magnet is over magnetised, and the readings at low currents become very much too high. In practice, short circuits, due to the failure of a fitting or piece of flexible wire, are by no means uncommon; and if, from such a cause as this, a fairly large fuse be blown, the meter is rendered highly inaccurate at low loads, and, as the occurrence of the short circuit will in all probability be unknown to the Supply Authority, the defect may remain undiscovered for a long time, and a considerable overcharge be made to the consumer. This constitutes a most serious drawback to an otherwise highly satisfactory and reliable meter, and it might readily be avoided, if the makers would but substitute a shunt winding for the permanent magnet, but for some unaccountable reason they will not do so.

Contrary to what one would expect, the mercury remains clean, and the meters start well with a single lamp after having been in use for years. This result is attained chiefly by exercising special care in the cleansing of the mercury before it is used in the meter.

The Chamberlain & Hookham meter is similar to the Ferranti in principle, but differs from it in several important respects. A magnetic field is set up by a tungsten steel permanent magnet, magnetised in position by exceedingly strong currents passed through a temporary magnetising coil once for all; no field, except a 'correcting' one, described below, being set up by the current to be measured. In the field produced by this magnet is placed a mercury bath, but a copper disc, immersed in the mercury, carries the bulk of the current. The current is introduced into the mercury, and led away from it, by two copper strips, placed immediately below the copper disc, which is slit radially for about one-third of its diameter all round, so as to confine the current to its central portion, which is in the most intense part of the field. The field being constant, the driving force is proportional to the current.

The spindle to which the disc is attached carries another copper disc outside the bath, which revolves in a field set up by the same permanent magnet; the effect of this is to oppose the motion of the motor with a force proportional to the speed.

One portion of the magnetic circuit of the brake field is much contracted, so that the iron is saturated; hence, since the motor and brake fields are in parallel with one another, it is possible to compensate for a considerable falling off in the strength of the permanent magnet.

The friction of the pivot is very small, being greatly relieved by the tendency of the copper disc to float in the mercury; the fluid friction, which increases with the square of the speed, is compensated for by taking the main current round a few turns on the brake field in such a sense as to lessen the braking effect.

This meter is exceedingly strong, convenient, and easy to fix, consumes practically no energy, is of considerable accuracy, and is not damaged by a

momentary short circuit; it is not complicated, and requires no attention when once fixed. It is one of the most serviceable meters in the market.

For alternating currents, the Chamberlain & Hookham meter comprises the same leading features as for continuous. An induction motor is substituted for the one with copper disc and mercury, but the brake disc is retained. A single disc is utilised for the motor and brake, and it is made of aluminium. In order to keep the brake field constant, it being supplied by a permanent magnet, a portion of the magnet is made of very contracted area, as in the continuous current meter; the iron is, in consequence, saturated at this portion of the magnetic circuit, and by a proper disposition of the circuit there is a good deal of leakage, so that a considerable variation in the strength of the magnet has but little effect on the field in which the disc revolves. A device is provided to prevent the meter starting without current passing through the main coil.

The Shallenberger meter is applicable to alternating currents only, and is one of the most widely used meters for this class of current. It is, in effect, an alternating motor consisting of two coils, with their axes set at an angle of 45° to one another, both surrounding a horizontal iron disc, free to revolve on a vertical axis; the plane of the disc is at right angles to the planes of the coils. One of these coils carries the current to be measured, the other is simply closed on itself. The current in the former induces in the latter a current which is a quarter of a period behind itself, and the effect of this is that the induced current, reversing as it does with the inducing current, attracts the poles successively set up by the latter, so producing continuous rotation. The motion is retarded by aluminium fans. In order to make the instruments direct reading, the angle between the two coils is adjusted until the desired speed is attained. The chief drawback to this meter is the somewhat large current required to cause it to start. Its simplicity is greatly in its favour.

The Thomson meter is a watt-hour meter, and is very largely used for both continuous and alternating supply. It consists of a motor, having its armature wound with fine wire, and excited with a shunt current, and its fields, without iron, by the main current. Since the field is proportional to the current, and the armature current to the pressure, the driving force is proportional to the watts, and, hence, the instrument is a watt-hour meter. As in the Hookham meter, the motion of the armature is opposed by a magnetic brake, consisting of a copper disc rotated by it in a constant field set up by permanent magnets, but, unlike the Hookham meter, no provision is made to compensate for variation in strength of the brake field. In order to help the starting of the instrument, a shunt winding is placed on the motor field, so as to nearly overcome the initial friction.

The meter can be made to give very accurate results, but it is open to several serious objections in practical use, viz.: (1) the commutator is liable

to become dirty, and cause the meter to stop ; (2) the friction may change, and the compensating shunt winding on the magnet become relatively too strong, so causing the armature to revolve without there being any current in the main coil ; (3) the extra resistance may become partially short-circuited, with the result that a large current flows through the armature, causing it to spin round at a very high rate.

A most interesting meter, recently invented by Messrs Evershed and Vignoles, which is hardly yet on the market, is similar to the Thomson, but possesses several important features which render it an admirable instrument, so accurate, indeed, that the Author employs it as a standard for checking other meters by.

It consists of a motor, similar to the Thomson, but without the shunt field winding, hence it cannot go without current in the main coil. It is possible to dispense with the shunt winding, on account of the manner in which friction has been diminished. The friction on the commutator is greatly reduced by making it of very small diameter, and with segments of round wires, and it can be made still less by making the segments of flexible wires, and employing roller brushes. The spindle, instead of carrying a worm gearing into a train, has a small coil through which is passed the current in the armature circuit, which is, of course, alternating. The effect of the field set up by this coil is to cause an iron ring, which embraces it, and is carried by a lever, to oscillate in time with the alternations of the current, which are slow, the full speed of the meter being only fifty revolutions per minute. This reciprocating lever drives the train. A magnetic brake is used, as in the Hookham and Thomson meters.

The sensitiveness of the instrument is marvellous, the meter starting with from $\frac{1}{500}$ to $\frac{1}{300}$ of full load, and having practically absolute proportionality throughout its range.

The possible variation in the strength of the brake magnets with lapse of time is provided for by means of an indicator, which responds to any change in field strength, and shows on the dial the correction to be applied to the meter consequent on the altered value of the field.

(2) The second class is that in which the current to be measured controls the registering mechanism, while a separate current supplies the motive power.

A considerable number of different meters on this principle have been made, but the majority of them have fallen into disuse.

One example, brought out some seven or eight years ago, has recently been re-introduced, viz., the Brillié. It comprises a watt-meter that is continuously restored to zero by the force exerted by eddy currents set up in a copper disc by revolving magnets, the motion of which is derived from a motor driven by a shunt current, controlled by a device actuated by the watt-meter.

The action is as follows: When no current passes through the main coil of the watt-meter, the motor circuit is broken, and no registration takes place. As soon as a current passes, the watt-meter is deflected, and a contact is made which completes the shunt circuit through the motor. This at once begins to revolve, and its speed to accelerate; the drag on the copper ring, mounted on the same spindle as the movable coil of the watt-meter, which is set up by the magnets revolved by the motor, increases with the acceleration, until it is sufficient to restore the watt-meter to zero, and in so doing to break the motor circuit. The watt-meter is then again free to deflect, when the whole cycle of operations is gone through once more. The result is that for each load there is a corresponding speed of the motor, the number of revolutions of which are recorded on dials in the usual way. The strong feature of the Brillié meter is that the portion of the apparatus which measures the power is practically free from all disturbing influences attendant on its having to control the registering mechanism. The result is that the starting current can be made very small, as it has only to cause the watt-meter to deflect and make the contact; once this is established, the motor is as powerful to move the train as if the maximum load were on the meter. As a matter of fact, if the adjustment for small loads be made too fine, there is danger that slight vibration may cause the contact to be made, and so the meter may register without current.

The chief drawback to the meter is the employment of a contact making device, the spark from which at breaking it is impossible to eliminate. There is also a weakness, common to all instruments using permanent magnets which are not frequently remagnetised, viz., inaccuracy introduced by changes in the strength of the magnets with lapse of time.

This instrument may be used either for alternating or continuous currents.

By far the most important instrument in this class at the present time is the new Aron meter, which is now self-winding; formerly it had to be wound up by hand, like a clock, and therefore belonged to the third class.

Essentially, the meter consists of two independently driven clocks, connected through a special gearing, which is so contrived that a spindle connected with it remains stationary so long as the clocks are synchronous; but, if one gains or loses on the other, the spindle rotates on an axis at right angles to its own, and drives a train of counting wheels.

In the simplest form of the instrument, one pendulum was an ordinary one, the other had a permanent magnet for the bob, and a coil carrying the main current, provided a field and accelerated the magnet, causing the clock which it controlled to gain on the other.

In the most recent development of this meter, both pendulums are made very short, only some four inches in length, and each carries a fine-wire coil, one pendulum being accelerated and the other retarded. In order to

eliminate errors due to faulty synchronism with no load, the current through the shunt coils is automatically reversed at regular intervals, while the motive power for driving the clocks is furnished by a shunt current, which automatically winds up a spring every half minute.

It is unnecessary to enter into the details of the mechanism, which, as will be obvious, is highly complicated. The clockwork is admirably made, and rarely gives trouble, but the reversing apparatus occasionally fails. The winding arrangement is undoubtedly the weakest point, and is the only serious drawback to the meter.

With the exception of the point referred to, the meter is an admirable one. It is exceedingly accurate at all loads, probably more so than any meter in the market; it will begin to register with any current, however small; it will not register without current, except to a very minute extent, and this is constantly corrected by the reversing arrangement; it is unaffected by external magnetic fields, owing to the astatic arrangement of the coils; finally, it is equally applicable to continuous or alternating currents, and can be adapted to five-wire or three-wire circuits.

(3) The third class is that in which the power required to drive the mechanism is derived from an external source. This class of meter is rapidly disappearing, owing to the great practical inconvenience of winding up the spring or weight from time to time.

The most important example is the older type of Aron meter, already referred to. This is being fast superseded by the new pattern, but a large number are still at work, and this class must not, therefore, be omitted.

A meter devised by Lord Kelvin belongs to this division. It is a combination of a weight-driven clock which automatically breaks the circuit when it requires winding, an ampère balance and an integrating cam. A fixed coil carries the main current, and in front of it is placed a fine-wire coil carried at the end of a vertical aluminium lever, free to turn on knife edges about a horizontal axis. The lower end of this lever has attached to it a train of counting wheels, the first one of which can roll on a cylindrical cam, which is kept revolving at a constant speed by means of the clock. When a current passes through the main coil, the other is repelled, and the rolling wheel, which originally stood clear of the cam, moves over it, is raised by it, and rolls on its surface, thus actuating the counting wheels. The cylindrical surface of the cam is cut away screw fashion, so that, when at one end of it, the wheel only rolls for a small portion of its revolution, and, at the other, remains on it for the greater part of a revolution, the time it remains on being proportional to the current corresponding to the position of the lever. A series of grooves are cut on the surface of the cam, so that, once engaged, the wheel cannot shift sideways.

The instrument is not suited to the rough conditions of ordinary practice, and has not met with favour.

(4) The fourth class covers what are usually designated electrolytic meters. This type is one of the earliest, but has hitherto not been taken up in this country, though in America the Edison meter has been employed to a considerable extent. At the present time, this type is receiving much attention, and two novel forms have recently been brought out. All such meters are, of course, applicable to continuous currents only.

The Bastian meter comprises a vertical cylindrical vessel, filled with acidulated water, and open at the top, the surface of the water being covered with oil to prevent evaporation. Two platinum electrodes, sealed into the bottom of a small tube down which the connecting wires pass, are placed at the bottom of the large tube. The current passes through the water, and decomposes it, liberating the gases which pass off into the atmosphere, causing the volume of water to shrink in consequence. The level of the surface falls, and its position is a measure of the quantity of electricity that has passed.

This method of utilising the electrolytic principle is exceedingly ingenious. The instrument is very simple and cheap, and has the advantage of registering very small currents.

The principal drawback is the heavy drop of pressure, no less than 3 volts at full load; this is sufficient to prohibit its use on 100-volt circuits, and even for 200-volt circuits the defect is a serious one. Another drawback, in practice, is the trouble of refilling the tubes, a meter reader usually belonging to the clerical staff, and, moreover, having no time to waste, even if competent to attend to the instrument. The evolution of gases which are mixed, and form an explosive mixture until diffused, is an objectionable feature. The glass tubes, also, are somewhat fragile.

The Schattner meter is another form of electrolytic meter. Here the current deposits copper from a solution of the sulphate of the metal. The diminution in weight of the electrode from which it is removed is actually weighed on a steelyard. Besides the inconvenience of this operation, the meter has the almost fatal objection that a portion only of the current to be measured passes through it, the greater portion of it travelling through a resistance connected as a shunt across the electrolytic bath. Variations of temperature, and variations in the conductivity of this bath, will of necessity introduce serious errors.

All meters, whatever the principle on which their action depends, should read directly in Board of Trade units on a vertical set of dials or on a scale. They should be arranged so that their accuracy at a given load may be tested in a reasonably short period of time, certainly not longer than half an hour. It is essential that provision should be made for sealing up the portion containing the mechanism, so that the authority responsible for checking their accuracy may secure the meters from being tampered with by the person fixing the instrument. It is equally important that the latter should be able to seal the terminals so that the consumer may not

interfere with them. For the actual sealing, the most secure material is sealing-wax; the most convenient, lead, pressed by a die.

The cases of meters should be of stiff metal, preferably cast, and they should fit water-tight, and, if possible, air-tight. Meters are usually fixed in cellars, and in similar situations where they are exposed to damp and dirt, and this must be kept in view in designing them.

The degree of accuracy to be aimed at should be as high as possible, but a laboratory instrument is neither necessary nor desirable. The following are the leading requirements usually specified by the Author:

Every meter must have an insulation resistance between the main or shunt coils and the case of not less than one megohm.

After a period of fourteen hours, during the first twelve of which a current equal to the maximum for which the meter is intended, and during the remainder a current 10 per cent. in excess of this, has been passed through the main coil, the temperature of any part of the meter must not rise more than 60° F. above that of the surrounding air. Every meter must stand a momentarily excess current of 100 per cent. without being damaged in any way, or its accuracy being impaired.

The loss in pressure in the main coil at full load must not exceed $\frac{1}{2}$ volt after the maximum current has been passing for one hour. The waste in the shunt coil, if one be used, must not exceed 25 watts for meters intended for currents up to 50 amperes, nor 50 watts for larger ones.

The meters must start and continue to register with one-hundredth part of the full load for which they are intended.

The indications of each meter must not differ from the true amount by more than $2\frac{1}{2}$ per cent. above or below at any load between and including $\frac{1}{10}$ and full load, nor more than 5 per cent. at $\frac{1}{20}$ load.

The indexes must be such that the total amount shown by each meter, without going through zero, shall be sufficient to cover the consumption at the consumer's installation at which it is fixed between two successive visits of the meter reader. The interval between these will, of course, vary in different stations.

It has been assumed that all the instruments described were to be used on two-wire circuits; it is frequently desired to place them on three-wire and occasionally on five-wire circuits. The current on a three-wire circuit may be measured by means of two two-wire meters of any pattern, or a single special meter may be employed.

In the former case, one meter is placed on each outer wire, the middle wire being left untouched (see fig. 104). To take an example, suppose the circuit be a three-wire one, with 100 volts on the lamps, then each of the two meters will be a 100-volt one. Suppose lamps on one side of the circuit only be alight, then all the current will return by the middle wire, and the arrangement will be the equivalent of an ordinary two-wire circuit.

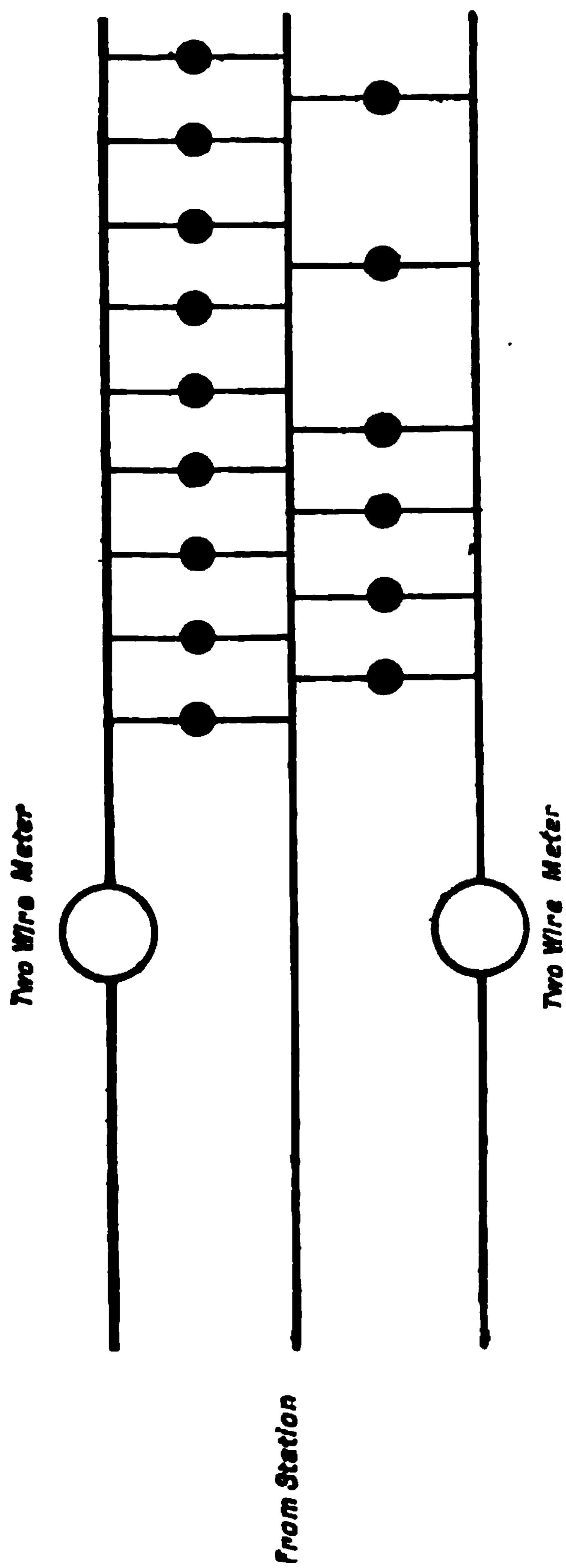


FIG. 104.—Arrangement of two ordinary meters for three-wire service.

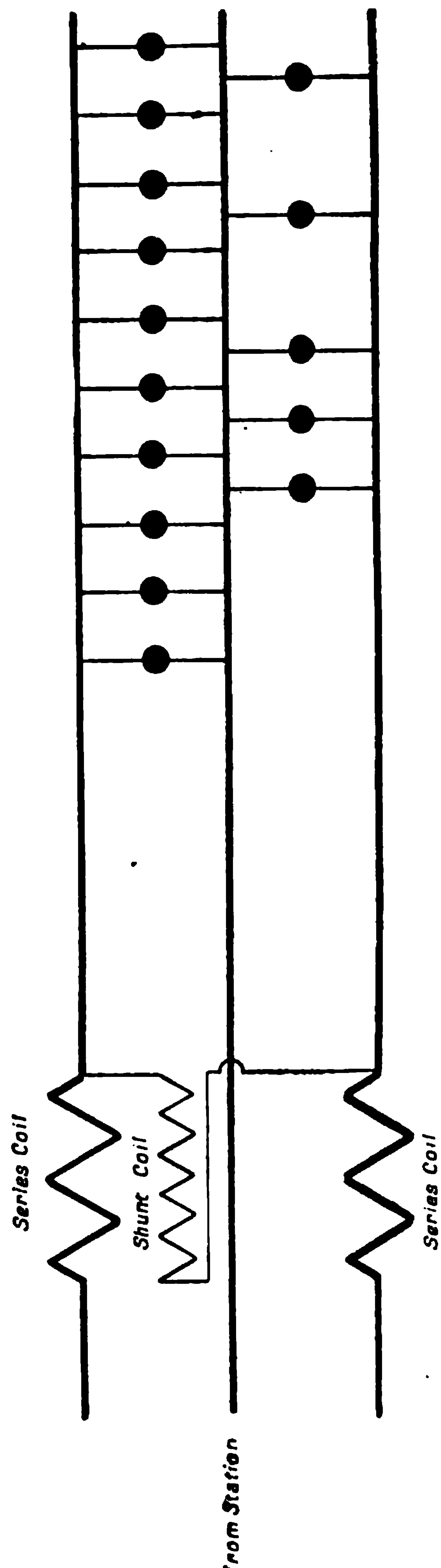


FIG. 105.—One three-wire meter for three-wire service.

Next, suppose lamps of equal number are alight on both sides, then the current passes through both meters, none returning by the middle wire. The quantity registered is thus double what it was before, which is obviously right. For different states of balancing between these two extremes, the record will be in proportion to the consumption.

If it be desired to use a single meter, it is only necessary to divide the main coil of a Thomson or an Aron meter, and take the current from each outer through one of the halves, the middle wire being left out of the meter, as before, and the shunt circuit being excited from the outers (see fig. 105). In this case, only half the coil is operative when lamps on one side only are alight, while the effect is double when those on the other side are turned on, and, hence, the registration is proportional to the energy used.

In the case of five-wire circuits, the measurements cannot be made by means of two-wire meters, and a special one becomes imperative. As before, the same two types of meter are available, the middle wire being again left out of the meter, and the shunt circuit excited from the outers (see fig. 106). In this case, however, the coils are divided into four, and the coils connected to the outer conductor are given twice the number of turns of those connected to the two intermediate wires.

Five-wire meters are very objectionable, partly because it is undesirable to have coils differing in pressure by 400 volts or more in such close proximity to one another; partly because the shunt circuit is apt to burn up, while, in addition, in the case of the Aron meter, the sparking on the winding circuit is greatly increased; and, lastly, because when the circuit is greatly out of balance, the unsymmetrical field given by the single coil gives inaccurate results.

It is best, for these reasons, to avoid the use of five-wire circuits, by measuring the energy at the point where the two-wire circuits, to which the lamps are actually connected, branch off from the five-wire system. In this case, four ordinary two-wire meters only are required (see fig. 107).

Practically the same objections apply to special three-wire meters when the pressure across the outers exceeds 250 volts, and it is then preferable to use two separate meters. Incidentally this course has the advantage of reducing the number of patterns of meter that have to be stocked.

The expense of using two or four meters, instead of one, might seem against the arrangement advocated, but actually the plan is substantially cheaper, as five-wire meters are exceedingly costly, and very liable to require repairs.

In fixing meters for ordinary two-wire installations, supplied from a network having the middle wire earthed, care must be taken to fix them on the insulated conductor, otherwise the consumer may obtain current without registration on the meter by connecting one of his conductors to earth, as will be evident from an inspection of figs. 108 and 109.

Following the example set by the suppliers of gas, the system of delivering certain definite quantities of energy for which prepayment has

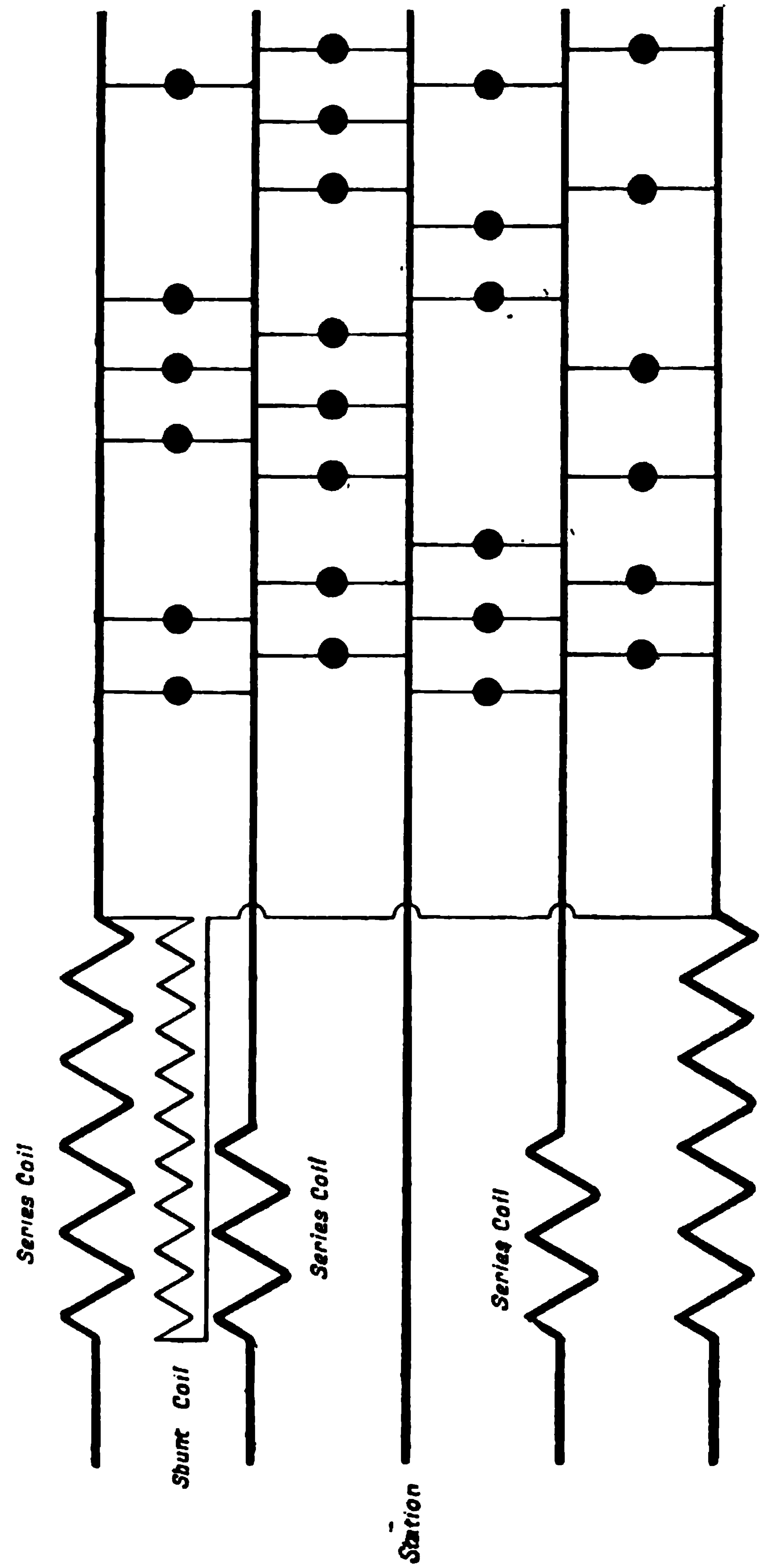


Fig. 106.—Single five-wire meter for five-wire service.

been made has been introduced, though so far very sparingly. The time is

hardly ripe; but, later on, when prices have become low, there is no reason why the phenomenal success attending gas prepayment meters should not be realised to a great extent in the case of electric supply.

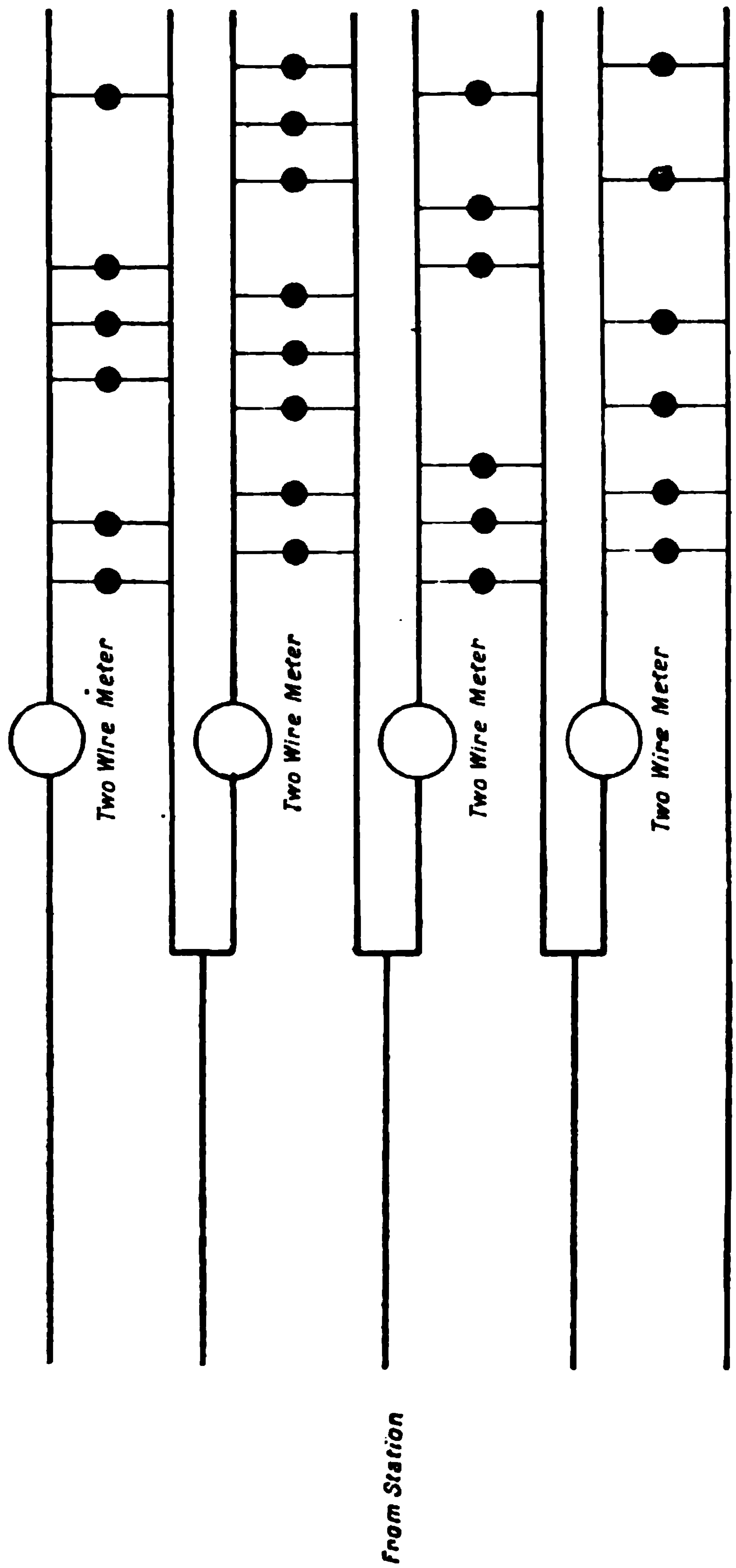


FIG. 107.—Arrangement of four ordinary meters for five-wire service.

What is required is a coin-freed switch to put on the current when the coin is introduced, and to shut it off when the stipulated amount of energy

has been consumed, and a meter to register the quantity of energy that has passed and determine the moment of opening the circuit. Much ingenuity has already been expended on apparatus for this purpose, but the matter need not be entered into.

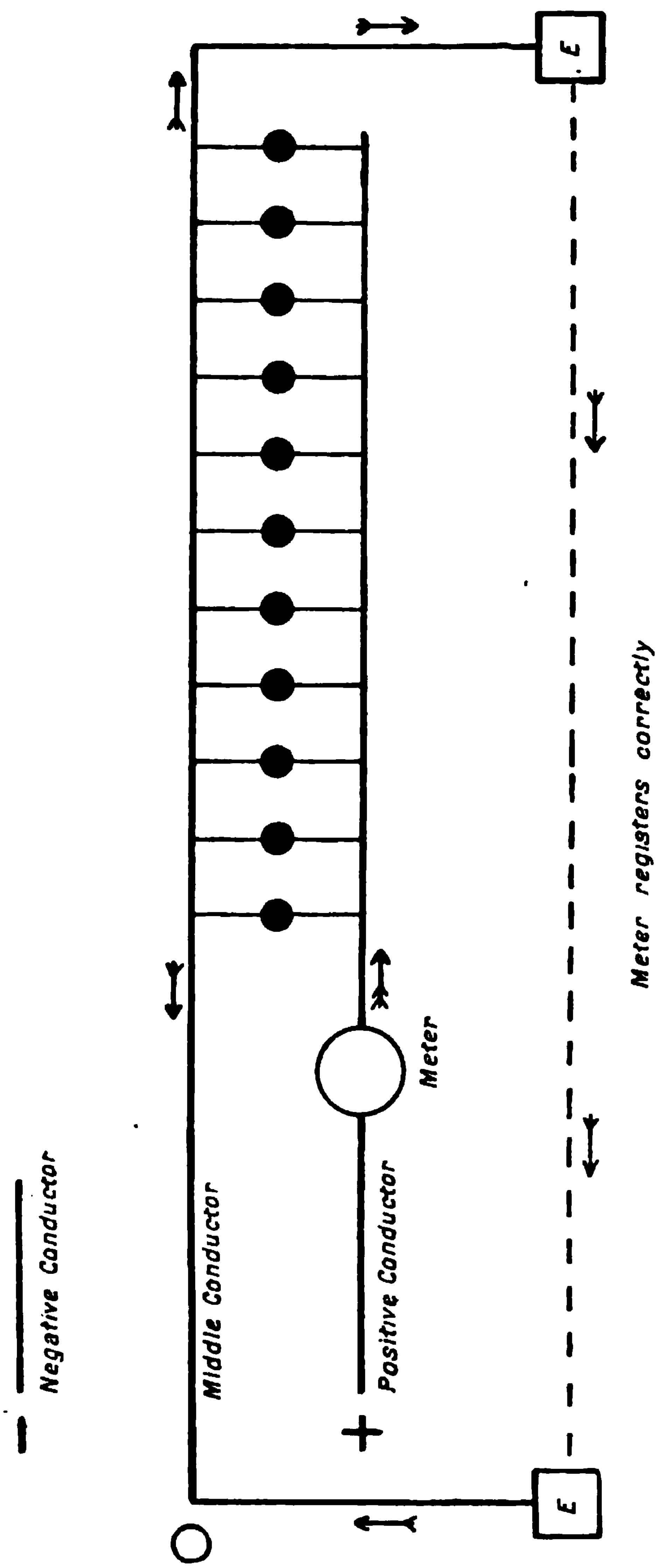


FIG. 108.—Meter on two-wire service supplied from three-wire network with middle wire earthed.

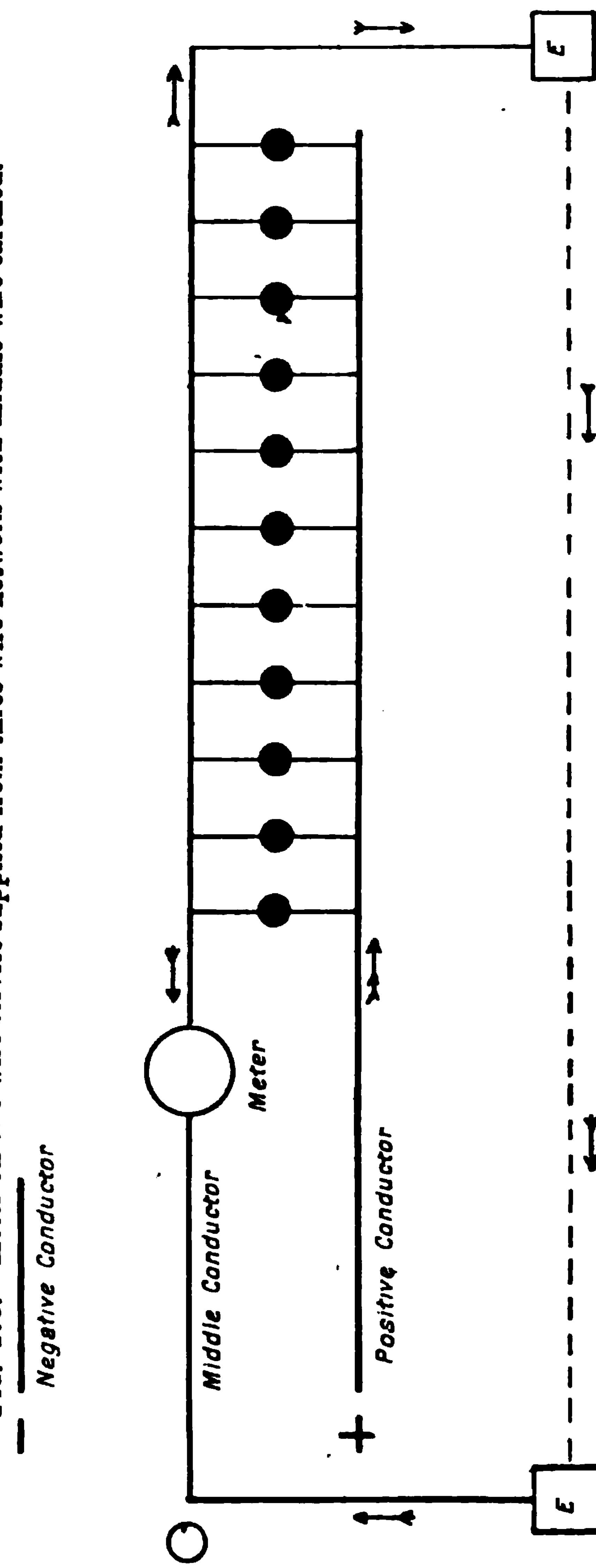


FIG. 109.—Meter on two-wire service supplied from three-wire network with middle wire earthed.

The question of charging a rent for the hire of a meter to a consumer is one that may be referred to here. It is frequently asserted that it is unfair to charge the consumer with the cost of measuring the energy he consumes,

and that Undertakers have no more right to charge for their meter than a tradesman has to make each customer buy a pair of scales to weigh the goods he purchases.

As to the legality of the matter, there cannot be the slightest doubt that the Undertakers are perfectly within their rights in charging a rent. The ordinary Provisional Order makes it incumbent on them to supply, fix, and connect up an appropriate meter, if required to do so by the consumer, provided that, 'previously to supplying any such meter the Undertakers may require such consumer to pay to them a reasonable sum in respect of the price of such meter, or to give security therefor, or, if he desires to hire such meter, may require him to enter into an agreement for the hire of such meter.' The consumer is thus not compelled to hire the meter, but may provide his own, if he prefer, the Undertakers in such case having facilities for checking its accuracy.

As regards the allegation of unfairness, and the supposed analogy between a meter and a tradesman's scales, it is to be pointed out that this does not hold in the slightest degree, since the tradesman need only provide one pair of scales for the whole of his customers, while each consumer of electrical energy requires a separate meter for himself, and, the instruments being expensive, the capital expenditure involved is very considerable.

The charging of a rent, then, is perfectly legitimate, and is quite justifiable; it is, therefore, merely a question of policy whether to do so or not. Undoubtedly the abolition of meter rents is very popular, and, in those towns in which no charge is made for gas meters, it may be well to concede the point; but, in other cases, it is to be recommended that the charge should be made, for it is only felt to any material extent by those consumers whose accounts are very small, and whose consumption, in all probability, does not cover their ordinary standing charges; they may as well pay the portion relating to meters, at all events.

The only other instrument, besides meters, ordinarily required in a consumer's premises, is one for recording the maximum power taken by his installation during a certain period. The object in view is to ascertain the greatest rate at which his actual steady consumption has taken place, and to take no account of any momentary increase of power, such as that due to a short circuit. In order to fulfil this condition, it is essential that the instrument should be sluggish, and not record an increase unless it last several minutes. Other requirements in such an instrument are, besides, of course, accuracy, (1) freedom from introduction of errors by vibration of the support; (2) freedom from errors due to inertia of moving parts; (3) simplicity; (4) cheapness.

The earliest instruments of the kind consisted of ordinary ammeters having an additional index attached, so arranged that, while it was carried forward by the ordinary needle, it did not return with it, and thus showed

the highest point it had reached. This type of instrument has many drawbacks. Its accuracy is affected by the friction of the extra index, and by the inertia of the ordinary needle, which is apt to swing past its proper position and so give too high a reading. It takes account of an instantaneous increase of current, and, in the event of a short circuit occurring, the index is almost certain to shoot to the end of the scale. Again, if the instrument be accidentally knocked, or if its support be subjected to vibration, the record is exceedingly likely to be destroyed.

This type fails in practically every respect to fulfil the required conditions.

The instrument that is now almost universally used for the purpose is Wright's 'Demand Indicator.' This consists of a vertical inverted U-tube, having a horizontal cylindrical bulb at one end, and an inclined bulb at the other. The former bulb is surrounded by a platinoid strip, through which the current to be measured passes. The tube, which is hermetically sealed, but not exhausted, contains coloured alcohol, which, when the instrument is at normal temperature, stands in a certain position in the U-tube, near the top of the side next the inclined bulb. When the current passes through the platinoid strip it warms the bulb, and the heat drives the alcohol down one side of the U and up the other, the liquid overflowing into the inclined bulb. When the current is shut off, the platinoid, and therefore the bulb, cools, and the liquid returns, but the portion which has run over into the inclined bulb is cut off and left behind, with the result that the liquid in the side of the U next this inclined bulb stands at a lower level than before, and the position of the end of the liquid in this tube is thus a measure of the maximum current that has passed. The tube is so supported that it can be rotated about the axis of the horizontal bulb, and the liquid then runs out of the inclined bulb into the tube, and the column returns to zero in readiness for a fresh measurement. In the latest form of the instrument, the liquid runs over into a graduated vertical branch tube, thus enabling the reading to be taken with the current passing.

This instrument fulfils practically all the necessary conditions; it is simple, cheap, unaffected by vibration, not liable to become deranged, and, by the nature of its action, is sluggish, while its moving parts are practically free from inertia; it is thus unaffected by shorts or instantaneous increases of current, such as arise at the moment of starting arc lamps or motors, and, finally, it is equally applicable to continuous and alternating currents. The degree of accuracy attained is probably not very great; though, the two bulbs being close together, the readings are not appreciably affected by changes of external temperature, yet they are necessarily influenced by the conduction of heat from the horizontal bulb to the other, though provision is made for minimising the error

from this source by interposing a metal wall between the bulbs and ventilating the portion of the case containing the inclined bulb. This instrument is undoubtedly the best for the purpose now in the market.

In low pressure distribution, the only other apparatus required on a consumer's premises consists of the main fuse for cutting off the whole installation, though this is sometimes supplemented by a main switch.

It is preferable to have a fuse contained in a separate case for each pole, so as to diminish the risk of a short circuit between two service mains through a fuse arcing badly.

One of the most satisfactory main fuses the Author has met with, and, at the same time, one of the cheapest, is that shown in fig. 110. The fuse is soldered into a stout brass washer at each end, the washer being the same

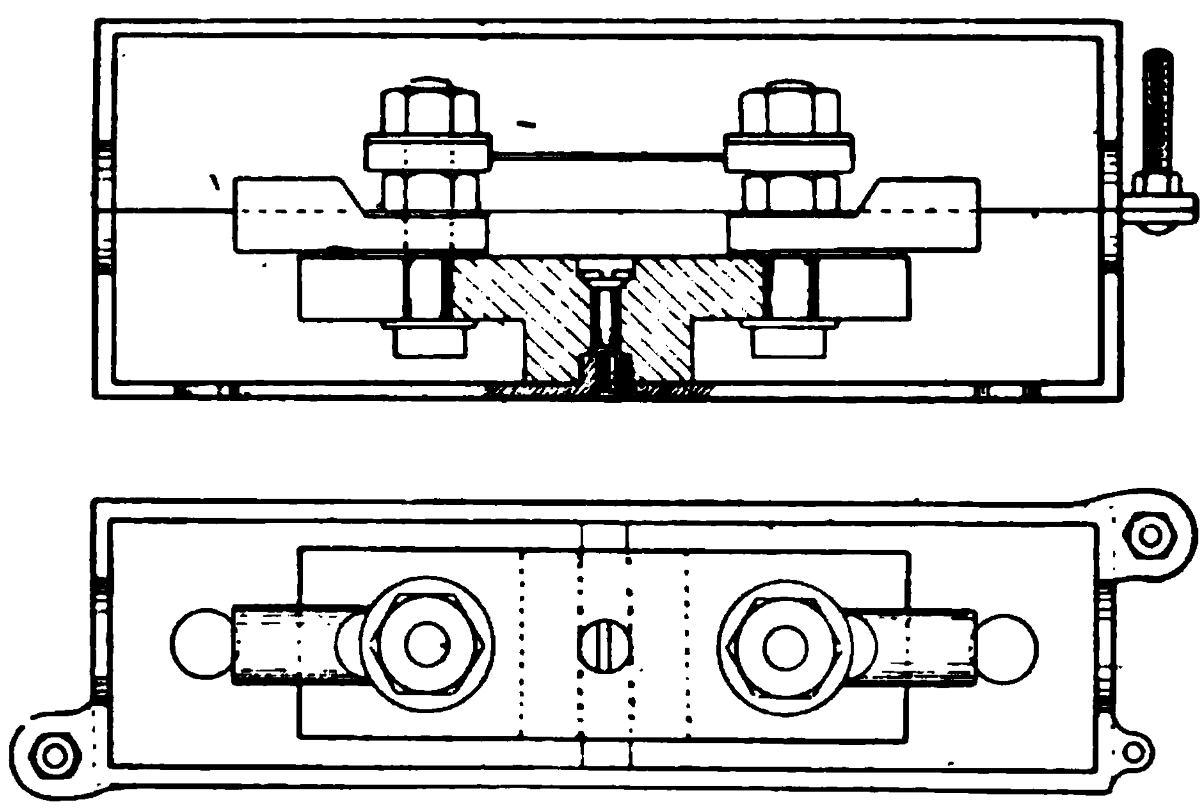


FIG. 110.—Main fuse.

for all sizes of wire. The washers are clamped to two terminals to which the main and consumer's wires are respectively brought, the distance apart of the terminals being the same for all sizes of fuse. The terminals are fixed to porcelain slabs, deeply undercut, so as to give very high insulation, and the whole is contained in an iron case, enamelled on the inside, and arranged so that it may be sealed. The holes through which the cables enter are blocked with conical rubber washers.

Another form of main fuse that is in extensive use has the fuses mounted in cast iron cases, with covers hinged in such a way that one can only be opened when the one next it is shut, the chance of an accidental short circuit being thus eliminated.

For circuits supplied at a pressure of 400 or 500 volts, which usually supply motors, a fuse having a magnetic blow-out is very useful and is always employed by the Author, except for circuits of several hundred horse-power, in which case the expense of an ordinary magnetic circuit breaker is justified.

Whatever fuse be employed, it must be capable of breaking a short

circuit on the service lines it is designed to protect when fitted with a fuse wire of the size proper for the installation.

For consumers' installations, the most suitable metal for fuses is tin. It melts at a low temperature, does not corrode quickly, and is reliable.

In multiple-wire circuits there should be independent fuses for each circuit connected to the intermediate poles so as to avoid the risk of opening the middle wire.

If switches be supplied, they should be arranged in such a manner that they can be worked by a handle projecting outside the case, the working parts being sealed up, and they should be of the double-pole type, and be capable of safely opening the circuit when a 50 per cent. excess of current is flowing at 50 per cent. excess pressure. Triple- and five-pole switches should be avoided, as, if one member controlling an intermediate conductor becomes dirty, or makes bad contact, the balance is immediately upset; it is thus preferable to have a separate double pole switch on each main circuit, all being coupled together, if desired.

All apparatus in connection with services should be standardised; the Author has found the following set of sizes very useful and suitable for all ordinary cases. The table shows the size of service main, size of pure tin fuse, with particulars of fusing currents, and size of meter for installations of different capacities. Everything is calculated to give a good margin for moderate extensions:—

Maximum Current required by Installation.	Size of Service Main, S.W.G.	Size of Fuse.	Fusing Current, Amperes.	Size of Meter, Amperes.
5	7 No. 17 S.W.G.	18 S.W.G. tin	15	5
10	7 No. 17 S.W.G.	16 S.W.G. ,,	25	10
25	7 No. 14 S.W.G.	12 S.W.G. ,,	50	25
50	19 No. 15 S.W.G.	10 S.W.G. ,,	80	50
75	37 No. 15 S.W.G.	double 10 S.W.G.	160	100
100	37 No. 15 S.W.G.	double 8 S.W.G.	240	100

The order in which the apparatus should be arranged, reckoning from the main, is fuse, switch, meter. A complete five-wire service is shown diagrammatically in fig. 111, this being the most complicated case likely to arise. In connection with these standard sizes of services and accessories, it may be of interest to state the proportion of the various sizes of meters in use in Manchester when the total number of 3335 was fixed:—

5 ampere,	14 per cent.
10 ,,	23 ,,
25 ,,	32 ,,
50 ,,	27 ,,
100 ,,	4 ,,

Like meters, fuses and switches must be sealed, the former so that no unauthorised person may replace or tamper with them, the latter so that

current may not be surreptitiously tapped off without passing through the meter. The cases should be of cast iron, and, for choice, should be enamelled on the inside.

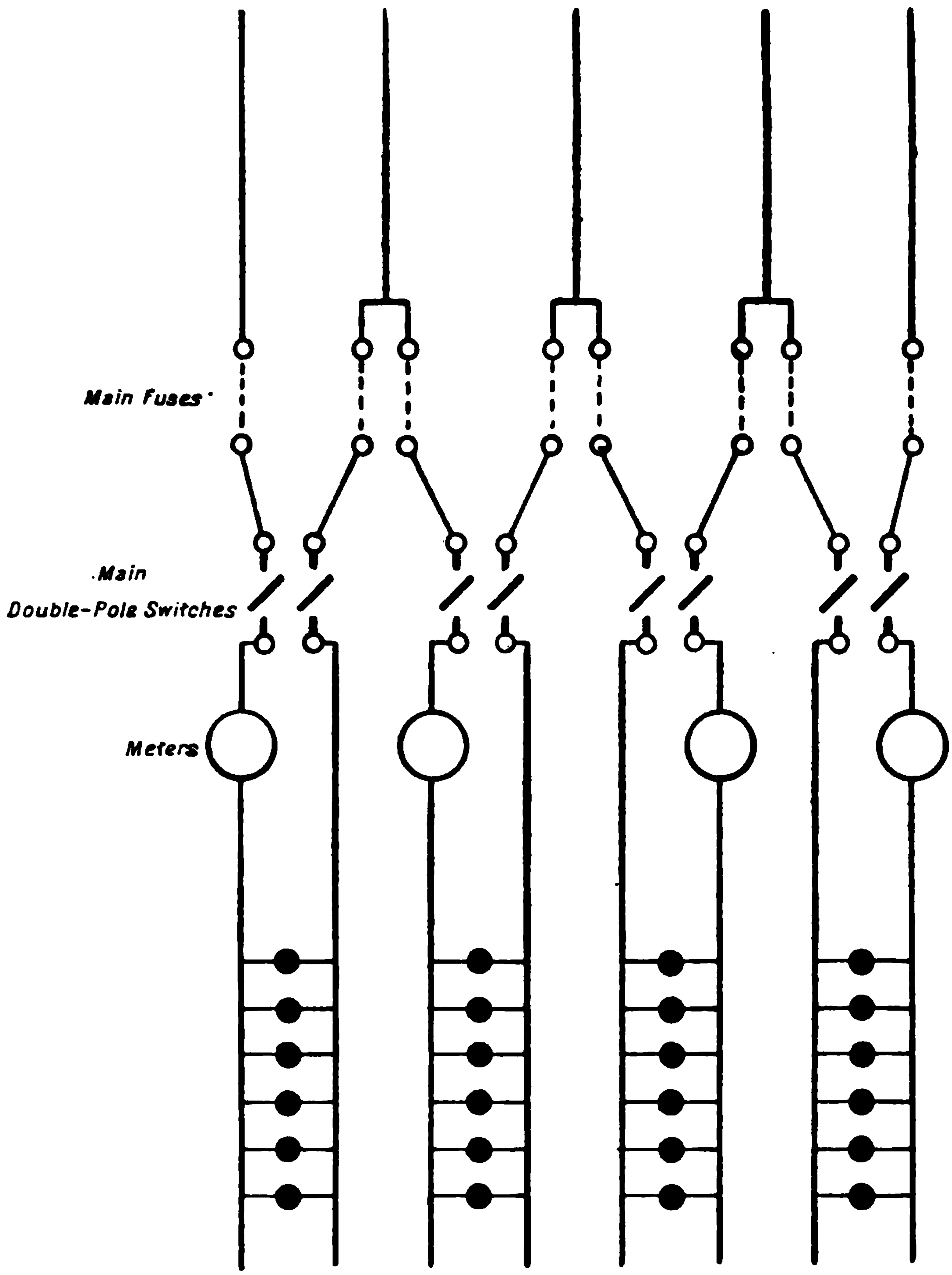


FIG. 111.—Arrangement of apparatus for five-wire service.

When distribution takes place by high pressure current, a high pressure main switch is essential, together with high pressure fuses. The latter must be of such a form that they can be replaced safely while the mains are alive, since the fuses have to be between the switch and the main to protect the latter against defects in the switch. The switch will, however, enable the

fuses to be put in when no current is passing. The switch should be arranged so that it may be operated with safety by the consumer, and so that he cannot tamper with it.

A transformer will, of course, be required. This should have its core and casing thoroughly earthed; considerable care is necessary to ensure this, since the laminations of the core are designedly slightly insulated from one another.

It is greatly to be preferred that all the high pressure apparatus should be contained in a small fire-proof room, but frequently it is placed in a cast iron case; if this is well earthed, it should be safe. The length of high pressure main on the consumer's premises should be kept as short as possible, and should be enclosed in an earthed armouring.

The Board of Trade require that some precaution should be taken to prevent the secondary wiring rising to a high potential in the event of the insulation between the primary and secondary coils of the transformer breaking down. One of the most widely adopted means for this is the use of the Cardew Earthing Device, in which two horizontal circular plates, the upper connected to the wiring in the consumer's premises, and the other to earth, are provided, and a piece of aluminium foil, shaped like a flattened dumb-bell, resting on the lower one. If the potential from earth exceeds a certain amount, the electro-static attraction of the plate on the tinfoil raises one end of it and connects the two plates together, thus blowing the main fuse if the increase in potential is due to leakage from the primary winding, as it almost necessarily will be.

A most ingenious house safety device was invented by Mr Ferranti some ten years ago, which, though it has never come into use, may well be described, since it fulfils no less useful a purpose than the automatic cutting off of an installation, if the leakage to earth exceeds a certain amount.

The instrument, which is applicable only to a system of supply using alternating current with house transformers, consists of two very small transformers (some 2½ inches square), having their primaries connected in series across the low pressure service terminals, the middle point being connected to earth. The secondaries are connected in opposition through an excessively fine and short fuse, from which is hung a substantial brass cone immediately over three contacts bored out to fit the cone. One contact is connected to earth and the other two respectively to the two poles of the service.

If, now, an earth develops on either conductor, the safety device transformer having its primary connected between it and earth, is partially or wholly short-circuited, the result being that the pressure given by its secondary falls while that of the other rises correspondingly, completely overpowering it, and sending a current through the fuse, causing it to melt and drop the cone within the three contacts, thus short-circuiting the main house transformer and connecting the installation to earth; the primary fuses instantly blow, and so cut off the whole installation from the mains.

CHAPTER XXVI.

STANDARDISING AND TESTING LABORATORY.

In every central station a number of measuring instruments are in use, and it is of vital importance that their indications should be accurate. Although, probably, no other class of instruments admit of such a high degree of accuracy being attained as electrical, it is, nevertheless, notorious that unless commercial instruments be frequently checked, they are more often than not inaccurate.

Perhaps the most important instruments, and at the same time those most often at fault, are voltmeters, for on their accuracy depends the correctness of the pressure given on the mains. The meters used for measuring the energy supplied to consumers, however, give rise to the bulk of the work of testing. Other instruments that have to be dealt with are ammeters, demand indicators, recording instruments of all kinds, resistances, insulation testing appliances, etc.

The purely electrical instruments enumerated, however, by no means exhaust the list of those that require attention. Steam pressure gauges, vacuum gauges, indicator springs, draught indicators, etc., all come within the purview of the standardising laboratory.

Besides measuring instruments, a number of electrical tests require to be made, such as the conductivity of copper wire or of gun-metal castings, the quality of carbons and incandescent lamps, the dielectric strength of porcelain or other insulators; the melting point of fuses, when made up from different materials and when fixed in various kinds of terminals, and, generally, the multifarious matters that from time to time need investigation.

In a large undertaking, an ordinary electrical testing room is not sufficient to meet the requirements. It is most desirable, even if not absolutely essential, to add a chemical laboratory for the purpose of testing the various stores used. The expense of the equipment and maintenance of this will be saved over and over again. In this laboratory should be tested the calorific value of the various coals offered by contractors; samples taken from the gases should be analysed; the oils offered for lubricating purposes should be exhaustively tested for chemical composition, density, viscosity, and flashing

point; the quality of cement supplied for culvert work or building extensions; and, finally, any materials that are used in the course of the working of the station.

In most stations the principal work of the kind to be done is the testing of consumers' meters. Experience shows that the makers' tests can but very rarely be relied upon for even a moderately large percentage of those supplied to authorities who are known to test the meters themselves, and the proportion in the case of those who do not is unlikely to be greater. It is therefore imperative that each meter should be tested carefully and for a sufficient time to ensure accurate results.

The tests which it is desirable to make are indicated in the last chapter; the most convenient way to carry them out will depend upon the type of

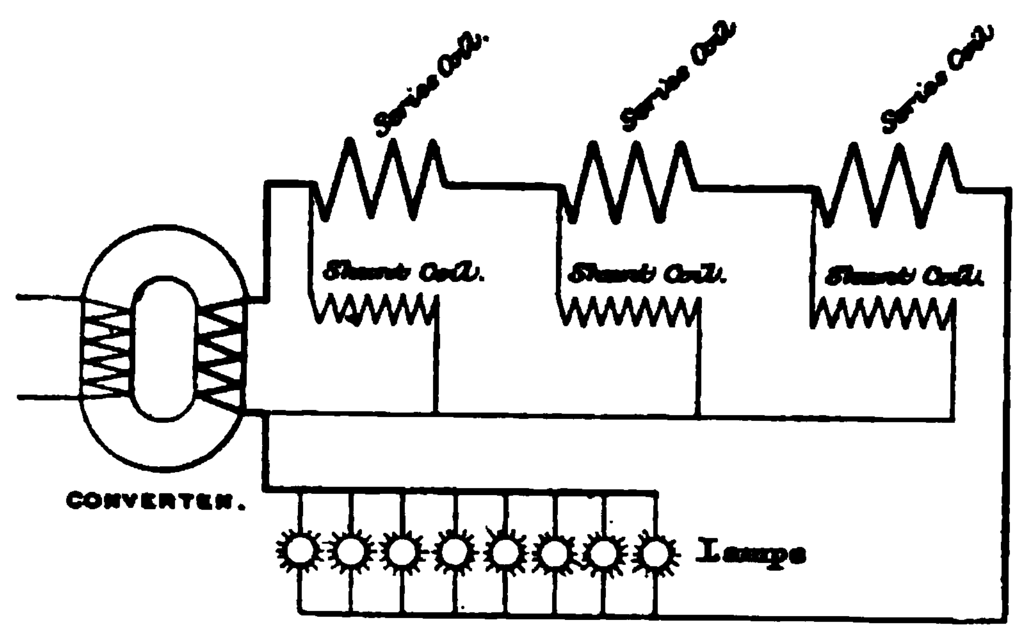


Fig. 112.—Faulty method of connecting meters.

meter tested. Most of those which consist essentially of a motor can be best checked by the number of revolutions of the motor itself being counted either directly or by means of temporary dials placed upon the earlier wheels of the counting train. In the former case, the value of the 'ratio wheel,' *i.e.*, the one used to make the meter direct reading, must be known. Tests made in this manner are useful for checking the proportionality of the meter at various points of its range; they should, however, always be supplemented by a prolonged test in which the readings are made on the ordinary dials. In some classes of meter this front dial test is the only one that can be made.

In order to economise current, and expedite the testing, a number of meters are strung together in series. With ampere-hour meters the same current necessarily flows through all, but with watt-hour meters this will not be the case, unless proper precautions be taken. When in use, the shunt winding has one end attached to the shunt terminal and the other to the mains side of the series coil. If a number of meters be connected in series, each being allowed to feed its shunt winding in the ordinary way, two errors will be introduced, as an inspection of fig. 112 will show: (1) With large

currents in the series coil, the shunt of the meter nearest the mains is the only one receiving its full pressure; the second has a pressure less than the full pressure by an amount equal to the drop of pressure in the main coil of the first; the third is deficient by the drop in two meters, and so on, the last of a long series receiving much less than the full pressure. (2) The last meter in the series, *i.e.*, the one furthest from the mains, is the only one that has flowing through its series coil the current that is measured; the last but one receiving in addition to this the shunt current of the last; the third from the end those of the last two; and so on to the one nearest the mains, which receives, in addition to the measured current, the sum of all the shunt currents of the other meters. These two errors are easily and completely disposed of by running a separate lead from the mains to excite the shunt coils, as shown in fig. 113.

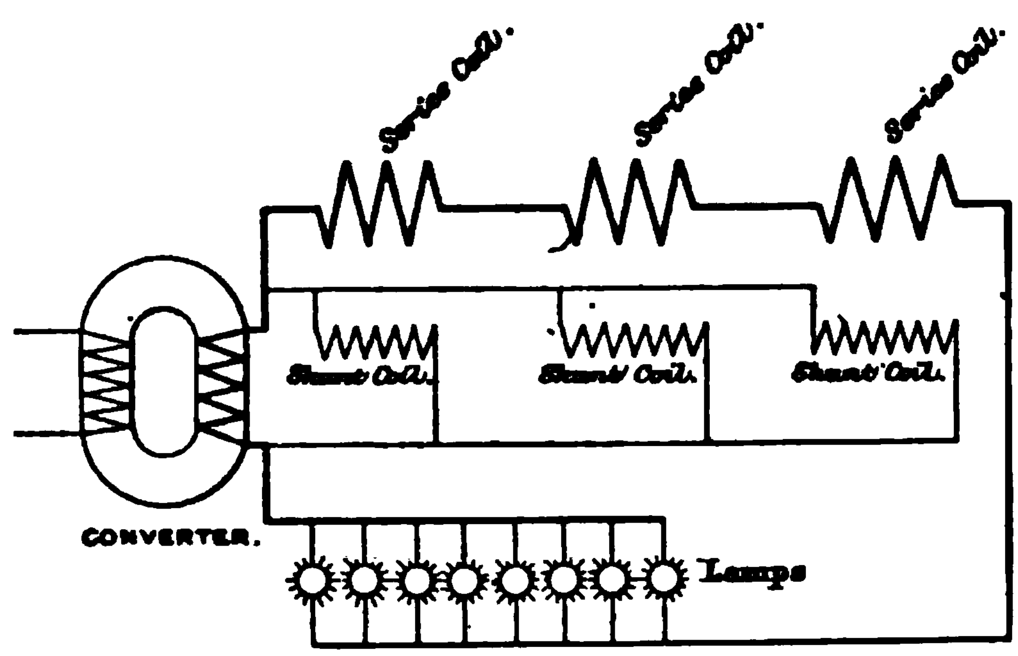


FIG. 113.—Correct method of connecting meters.

When readings on the ordinary or temporary dials can be taken, the indications are all noted, and the desired current is thrown on and kept on for a sufficient time to obtain a reading of such a magnitude that an error of $\pm 0{\cdot}1$ of a division would not affect the reading more than one per cent. It is then thrown off and the readings again taken when the meters have come to rest. The pressure, and therefore the current, is maintained as closely constant as possible during the run.

Obviously, there is a slight error in this method when applied to meters that are themselves motors, owing to their requiring time to get up speed, but this is compensated for in practice by their taking approximately the same time to slow down after the circuit is broken.

It is important to note that the ordinary dials of a meter are very rarely divided accurately, and misleading results may be obtained on this account. The best way to eliminate this error is to run the meters for such a time as to allow the index to go exactly round once, but this cannot always be done.

In those cases in which the revolutions of the motor itself are counted

directly, the meters are allowed to obtain their full speed with the desired current before the counting is begun; this is essential, because the number of revolutions noted is comparatively small.

The three quantities to be measured are the pressure, the current, and the time.

The pressure has to be kept constant during any one run, and, as devices for effecting this have usually to be adjusted by hand, the instrument employed should have a large, clearly marked dial. For alternating currents, a Cardew voltmeter, in which the wire is carried by a tube, compensated for changes of temperature and forming the case, placed horizontally, is most convenient and very fairly reliable. For continuous currents, a moving coil voltmeter is well adapted to the purpose. For accuracy, an electro-static voltmeter is excellent for either class of current. Whatever form of voltmeter be employed, it should be frequently and periodically checked against Clark cells.

The current is best measured by an easily read ammeter, frequently checked against a standard. For alternating currents, Kelvin balances are very free from error, but require a little practice to manipulate. For continuous currents, a moving coil ammeter is the most suitable instrument.

For measuring the time, a loudly ticking clock, preferably with a long visible pendulum beating seconds, is very suitable, and, in some cases, it is convenient to have a contact-making device to sound a gong at each minute, when desired. A number of watches showing seconds and minutes up to, say, thirty minutes, but without hour hands, are useful.

The magnitude of the currents used is often very great, but, inasmuch as the resistance of the meter coils is low, the pressure required is not high; the lowest that will send the required current through the string of meters should be employed, but a certain amount of margin should be kept in hand.

The source of the current will necessarily be transformers when alternating current meters are to be tested. One transformer giving a large current at a pressure of 15 or 20 volts will be required for the main coils; and another giving a small amount of current at the usual pressure of supply, for the shunt coils. For continuous current meters, the current should unquestionably be derived from a secondary battery for the main coils, and preferably for the shunt coils also.

The pressure may be kept steady in various ways. With alternating currents a transformer having a number of connections brought out at different points of its low pressure winding, and taken to a suitable switch, is very convenient. If cells be used, their number may be varied for coarse adjustments, and a resistance be used to give fine. If preferred, a booster may be employed.

For absorbing the current, some form of resistance is required; in the case of alternating currents, it is imperative that it should be non-inductive.

Lamps run considerably below their proper voltage have much to recommend them, if the pressure be of the order of 100 volts; if much lower, wire resistances are preferable, but great care must be taken to wind them non-inductively. Water resistances are quite unsuitable, as they are variable and troublesome. The resistances should be well insulated to avoid any undetected leakage taking place.

In designing the meter testing room, provision should be made for a number of separate testing circuits, so that several groups of meters may be got ready simultaneously, and several of these groups be tested at once.

A very complete testing plant, designed by the Author some years ago for the London Electric Supply Corporation, may serve as an example of an arrangement suitable for dealing with a large number of meters.

Four testing circuits were provided. The first circuit was intended for running meters at full load, to test whether they became unduly hot. This was supplied from a transformer giving current at 10, 20, or 30 volts at will, the lowest pressure that would give the desired current through the circuit being used.

The three other circuits were all for testing the accuracy of the meters, and, as there were frequently a considerable number of meters having a rather heavy drop in their main coils to be tested, they were supplied at a pressure of 100 volts from a transformer giving a current of 300 amperes.

The pressure was kept constant by means of a subsidiary regulating transformer, having its secondary in series with that of the main transformer. It would give 300 amperes at 9½ volts, and connections were made at ten points of its secondary, so as to obtain the current at a pressure of ½, 1½, 2½ to 9½ volts. By means of one two-way and one ten-way switch the pressure could be varied 9½ volts by steps of ½ volt. In the primary circuit of the regulating transformer was a reversing switch, so that this transformer could either help or oppose the main one, thus giving a range of 19 volts.

Two of the circuits were identical, each being provided with resistances, having a conductivity of 1·11 mho divided into three sets, one of 1 mho having ten steps of 0·1 mho each; one of 0·1 mho divided into ten steps of 0·01 mho each; and one of 0·01 mho divided into five steps of 0·002 mho each. Each set of resistances had its members brought to a switch, which, by the rotation of a hand-wheel, joined the desired number of resistances in parallel one after the other. In this manner any current up to 111 amperes could be obtained by steps of 0·2 ampere.

The third circuit was similarly arranged, but the resistance had twice the conductivity, and the steps of the adjustment were 0·4 instead of 0·2 ampere.

The switches were of somewhat special design. One with ten contacts, each carrying ten amperes, is shown in fig. 114. It had eleven ring contacts projecting radially round a semicircle. The first contact was of sufficient size to carry the whole current passing through the entire resistance in parallel to

which it belonged, while the other ten were in each case adapted to the current that flowed through each member of a set. A brass sector, worked by a hand-wheel, insulated from it, subtending the same angle at the centre of the switch as the eleven contacts, was so placed that when the hand-wheel was moved continuously in one direction, it was forced successively through all the ring contacts, thus connecting the ten, one after the other, with the first. The position of the hand-wheel thus determined the number of coils in parallel, so dispensing with the annoyance experienced when a number of separate switches are used, and an effort of memory has to be made to remember which switches allow the desired current to pass; moreover, at full load, there is no idle wire.

Scale.—1/6th Full Size.

FIG. 114.—Switch.

The resistances employed were wire spirals of platinoid, no wire exceeding $1\frac{1}{2}$ millimetre in diameter, the object being to allow them to attain their final temperature rapidly. The coils carrying ten amperes were of No. 17 B.W.G. bare wire, wound in two oppositely directed spirals, carried on porcelain insulators in a wrought iron frame. The coils for the smaller currents were of insulated wire, wound on zinc cylinders about $3\frac{1}{2}$ inches diameter, split parallel to their axes to eliminate eddy currents, each spiral being wound half in one direction and half in the other.

The current was measured by three Kelvin balances, reading to 10 amperes, 100 amperes, and 600 amperes respectively. Since all these were required on each testing circuit, but only one at a time, a gridiron switch was arranged, the balances being connected to vertical bars and the

three testing and the heating circuits to horizontal; two extra vertical bars admitted of one circuit (usually the heating) being run without a balance, and of changing from one balance to another without stopping the run.

Single break switches enabled any circuit to be closed or opened at will at a definite instant.

A horizontal, tube pattern, Cardew voltmeter was used for measuring the pressure.

All connections between various parts of the circuits were made by means of bare copper.

The number of meters of any kind that require to be tested simultaneously is constantly varying, and if two fixed terminals only be provided between which to join them, a number of different lengths of cable for connecting them thereto are required, and these are clumsy and unsightly. This difficulty was got over by means of a series of brass bars about 2 feet 6 inches long, having studs and nuts projecting at intervals of 8 or 9 inches, fixed against the wall above the shelf on which the meters were placed; bridging pieces served to bridge across the gaps when necessary. Short pieces of very flexible cable, terminating in brass eyes, were used to join the ends of a set of meters to the nearest bolts of separate bars. On removing the bridging piece connecting the bars, the meters were looped in. This arrangement was found most convenient in practice.

The arrangement of the whole of the testing plant described is shown diagrammatically in fig. 115.

This particular plant has been described in detail because of its completeness and also because it may serve as a model, with modifications that can readily be devised, for any testing requirements, whether for alternating or continuous currents.

When demand indicators have to be tested, exactly similar arrangements will suffice, the same or additional testing circuits being employed.

Ammeters also are similarly provided for, and such articles as fuse wires, magnetic cut-outs, etc., can all be dealt with.

We have now to consider the apparatus necessary for making delicate measurements and for checking the sub-standards used in the rougher testing.

The following instruments are to be recommended:—

A first-class high-resistance reflecting galvanometer, preferably ballistic, complete with suitable shunts.

A dead-beat reflecting galvanometer of the so-called D'Arsonval type.

A platinoid or manganin bridge of dial pattern, with ventilated coils having ratio arms of 1000, 100, 10, and 1, and resistances ranging from 0·1 to 10,000 ohms, adjusted for legal ohms.

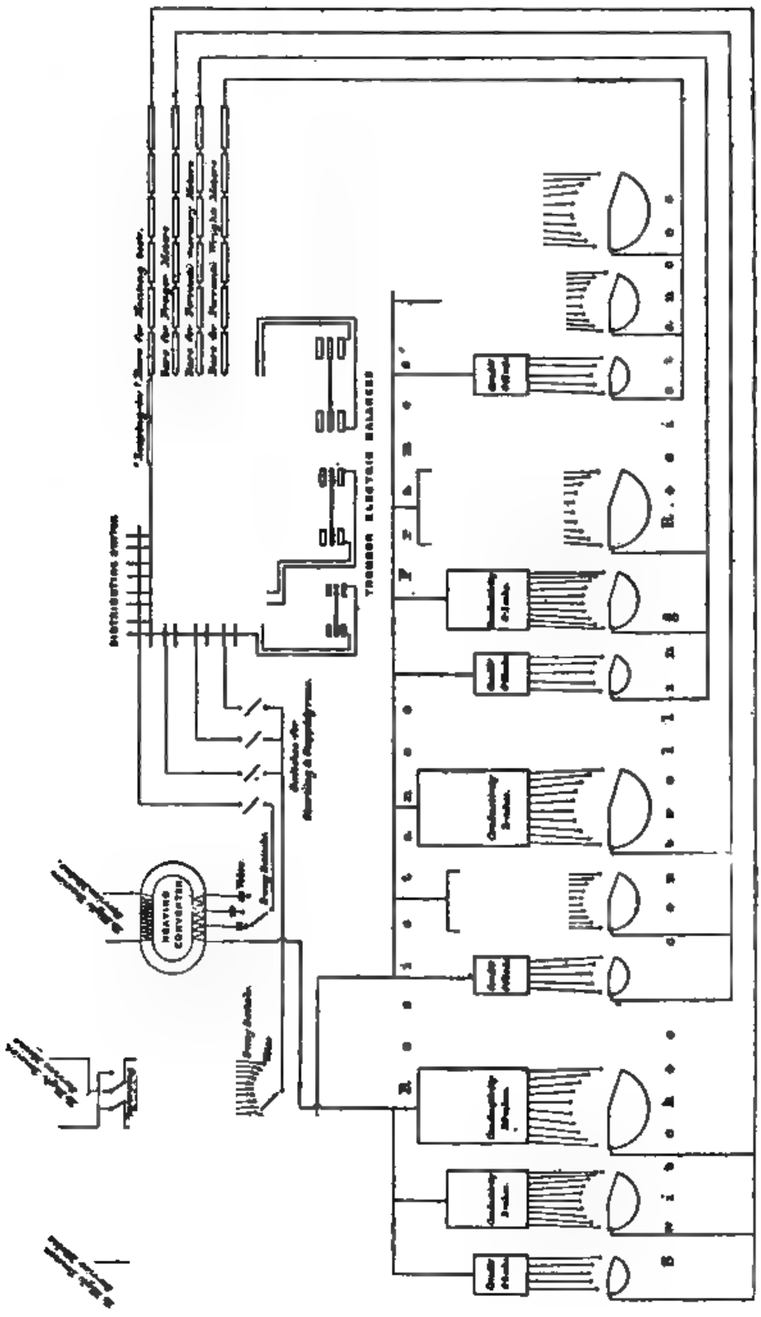


FIG. 115.—Testing plant.

A standard legal ohm.

A resistance of one megohm, though not essential, is very useful, and saves much time in making insulation tests.

Standard low resistances capable of carrying large currents. One of 0·1 ohm carrying 15 amperes, one of 0·01 ohm carrying 150 amperes, and one of 0·001 ohm carrying 1500 amperes.

A condenser of adjustable capacity from, say, $\frac{1}{10}$ to 1 microfarad.

Three pairs of standard Clark cells.

One potentiometer. This instrument will enable measurements of the highest degree of accuracy to be made on any instrument that it may be desired to check, and is invaluable; it is so well known that it need not be described here.

A battery giving about 500 volts. The type of cell ordinarily used is the Leclanché, and this gives excellent results, though it is somewhat troublesome to maintain. Dry cells are far more convenient, and those of the Obach type are probably the best adapted of any to the purpose. They should be thoroughly well insulated, and the connections be examined from time to time to see that they are tight.

With the above outfit it is easy to make practically every electrical measurement that is likely to be required with the highest degree of accuracy.

It is unnecessary to enter into details of the arrangement of the apparatus, but a few remarks may be made as to the testing room. It should be well lighted, except for a portion that can be shaded for reading the instruments. Reflecting instruments should be provided with translucent scales, and be so arranged that the spot of light is large with well defined line.

If vibration of the building is unavoidable, its effects may be got over by suspending the instruments from rubber cords.

The apparatus used for checking the sub-standards should never be allowed to leave the testing room; and, to minimise the temptation to depart from this rule, the instruments should be securely fixed in their places as far as practicable, but in such a manner that they can be readily cleaned.

For insulation tests, it is well to mount the testing apparatus on solid blocks of white paraffin wax, taking care to scrape the surfaces from time to time.

Testing keys may, with advantage, be enclosed in cases, the finger piece only projecting; in this way much dirt is kept out and the insulation maintained, while the liability to unpleasant shocks, when testing with high battery powers, is avoided.

The most suitable wire for making connections with is undoubtedly that insulated with pure gutta percha. In time, the insulating material will perish and crumble away, but while it lasts it is highly satisfactory

and the cost of renewal is not great. The wires should be so run that they can be readily distinguished in case they have to be traced out.

So far as the chemical portion of the laboratory is concerned, the most important part of the apparatus is a thoroughly good chemical balance. In addition to this, the ordinary furnishing of test tubes, beakers, burettes, retorts, and a stock of reagents in common use are required. A series of hydrometers for testing the specific gravity of oils, etc., will be necessary, and apparatus for measuring the calorific value of fuels.

CHAPTER XXVII.

SECONDARY BATTERIES.

The great cost involved, and, collaterally, the risk of failure of supply entailed by the necessity for producing electrical energy at the rate at which it is being consumed, has caused a large amount of attention to be devoted to the devising of some means for storing electrical energy.

The only way so far invented consists, not in storing electrical energy, *qua* electrical energy, but in converting it into chemical energy and reconverting it as and when required into electrical energy; in order that this conversion may be effected, the electrical energy must be under pressure in the form of continuous current.

The only type of cell in commercial use consists essentially of two lead plates immersed in dilute sulphuric acid, one plate being in the condition of spongy lead, the other being coated with lead dioxide. There is an almost endless number of variations of this one type, but the differences are merely matters of detail and relate chiefly to the way in which the plates are built up and the coating formed.

It is unnecessary to enter into a description of the various forms. Some possess distinct advantages, others have practically nothing to distinguish them beyond some trivial detail; but, on the whole, the general result of the work done since the first invention of the lead cell has resulted merely in the durability of the plates being somewhat improved and the general working made more reliable.

This is but a disappointing result for a vast amount of labour and research, for no radical departure has been made since the original invention. There is, however, no law of nature against the development of far more satisfactory means of storage, and one cannot but hope that some experimenter may light upon it. In the meantime it is quite justifiable, nay, more, it is only prudent, seeing the enormous advantages attending cheap and efficient storage, to lay down systems of supply in such a manner that advantage can be taken of secondary batteries, while, even at the present time, in spite of their manifold defects, batteries may be used with material advantage in many cases.

All varieties of the cells in use labour under certain disadvantages Lead being the basis of all, the first cost is necessarily very high; while, however well the plates may be formed, the active material drops off and the

deterioration of the cell is rapid, the cost of maintenance being in consequence heavy. Added to this, the efficiency of the conversion of energy is low, being only about 80 per cent., thus increasing the running cost. This is still further augmented by the onerous conditions of central station supply, it not being feasible to arrange for the best mode of charge and discharge on which the durability and efficiency greatly depend.

It is thus clear that the present position is that, while it is possible to store electrical energy, it can only be done at great initial capital cost and by incurring a heavy loss on the amount stored, and considerable expense for upkeep of the storage plant.

In the early days of electric supply, batteries were looked upon as furnishing the means of providing a reserve in case of breakdown of the generating plant, but now that the field of operations has so greatly increased, the enormous capital cost of batteries places them quite out of the question as a reserve, except in very small stations, and practically no reliance is placed upon them for this purpose at the present time.

The field of usefulness for batteries, in consequence of their heavy cost, is confined chiefly to equalising the load on the generating plant, and here the scope is great, in spite of the expense.

There are two kinds of equalising, viz.: (1) The equalising of the load over comparatively long periods of time, affecting the maximum rate of working of the plant; and (2) the prevention of instantaneous variations of load, relieving the generating plant from sudden shocks.

The variability in the load on a central station is one of its most marked features, and is fully referred to later on. It is obvious that, for a given quantity of energy delivered in a given period, the maximum rate at which it is delivered may vary enormously; the whole quantity might be delivered in a small fraction of the period, the maximum power being then very great and much in excess of the mean, or the rate might be uniform throughout the period, in which case the maximum and mean power would be identical.

Now, the first cost of the generating and transmitting plant depends on the maximum rate of working, and the greater the number of links in the chain between the coal and the energy delivered over which the equalising can take place the greater is the economy introduced. This points, therefore, to the placing of the batteries as near as possible to the consumer. Theoretically, the maximum advantage would be derived by providing each consumer with a battery; practically, of course, this is out of the question, but a near approach can be made by having battery sub-stations at various points on the network.

In order that this course may be followed, it is imperative that the current distributed should be continuous current, and this is a most cogent reason for its employment on the network. It is frequently asserted that

batteries can be used with alternating current systems, the batteries being charged at the generating station through the intervention of a transformer and rotatory converter or of a motor-generator, and discharged into motors driving the alternators.

Such a statement shows an inadequate appreciation of the conditions of the problem, for, although of some utility, a great portion of the advantages of storage are thrown away. The equalising effect is confined to the boilers, engines, and dynamos, the full amount of variation still taking place on the feeders and transformers. Furthermore, the capacity and maximum discharge rate of the battery must be augmented by the amount of energy wasted in transmission between the generators and the distributing mains and by the increased rate of working required by the losses respectively. The economy is still further diminished by the fact that this greater amount of energy having to be converted by the battery, the loss due to the waste in the battery itself is augmented.

One most important portion of the equalising effect of a battery is the provision it affords for hours of very little load. In nearly all stations the load between, say, midnight and 6 a.m. in winter, or 8 a.m. in summer, is exceedingly light, and the saving and convenience of being able to shut down the generating plant between those hours is very marked. In the case of a large district, served from sub-stations supplied with multi-phase current, the saving may be very great through the avoidance of the light load losses in the alternating feeders. In this case, the batteries would be placed in, say, every other sub-station, or in one in three or even four, the districts normally served from the other sub-stations being supplied at night from those with batteries.

So far, we have considered the effect of storage in making the drain on the generating plant more even over considerable periods. The facilities it gives for dealing with sudden variations in load of short duration are most valuable in saving the plant from strain and in maintaining a uniform pressure. The action of the battery in such a case is that, while the conditions are normal, it is steadily charging; while, immediately a sudden increase in demand takes place, the battery not only ceases charging, thus allowing the new load to be substituted on the generator for its own, but automatically and instantaneously contributes the energy stored within it to the supply. This use of a battery is of special use when large motors are supplied from the same mains as lighting, and also in the case of a station supplying a moderate number of tramcars.

Incidentally, batteries are convenient, as they give an easy and efficient means of varying the pressure, and enable balancing machines to be dispensed with on multiple-wire networks, though their defects go far to neutralise these advantages, difficulties being met with in charging cells which are not equally discharged.

In the operation of batteries, there are a number of different ways in which they may be actually applied to the network. Inasmuch as the pressure required to charge a cell fully may be as much as 2·6 volts, while during discharge the pressure of the cell may be 1·8 volt or less, it is obvious that in all cases some means must be adopted for raising the pressure on the battery while charging is proceeding; while, if constant pressure is to be given to the circuit during discharge, some method must be adopted for regulating the pressure given by the battery.

A common method, applicable whether the battery be fixed at the station or at the end of a feeder, is shown diagrammatically in fig. 116. The cells are all connected in series, and are sufficiently numerous to give the normal pressure across the outers of the network when discharged to their lowest pressure. To the middle point of the series is connected the middle wire of the network, assuming, for the sake of simplicity, that a three-wire system is in use; the last ten or twelve cells at each end are connected to switches known as regulating switches, the cells themselves being called regulating cells.

A regulating switch consists of two bars, each of which, by means of an arm or brush, can be connected with any one of a series of contacts, each such contact being connected to the junction between two successive cells. The brush is usually divided into two parts, connected through a resistance, so as to avoid short-circuiting a cell as the brush bridges across two contacts.

To one bar, called the discharge switch of the regulating switch, is connected one of the outer conductors of the network; and to the other bar, called the charging switch, the conductor of the same polarity of the feeder, or of the generator direct if the battery be fixed at the generating station.

The mode of operation is as follows:—The charging switches are set so that the feeder is connected to the extreme regulating cells on each side, the whole battery being thus included; the discharge switches are set to include a sufficient number of cells to give the required pressure on the network. The generator is run at the pressure required to charge the cells quite independently of the pressure on the circuit. The end cells, being the least discharged, become fully charged before the others; as this occurs, they are cut out one by one, by moving the charging switches away from the ends. It is clear that the switches must be so operated that the charging switch is never further from the end cell than is the discharge switch, or the cells intervening will be reversed.

When the battery is fixed at the generating station, it can be used to regulate the pressure on a number of feeders, the arrangement being similar to that described, each feeder having its own discharge switch enabling it to be connected to that particular regulating cell giving the pressure appropriate to it.

In certain cases, it is not convenient to vary the pressure given by the generator, or it may be necessary to charge the cells from the network on which a constant potential is maintained. In this case, the pressure is raised to the requisite extent by means of an independent machine, to which the

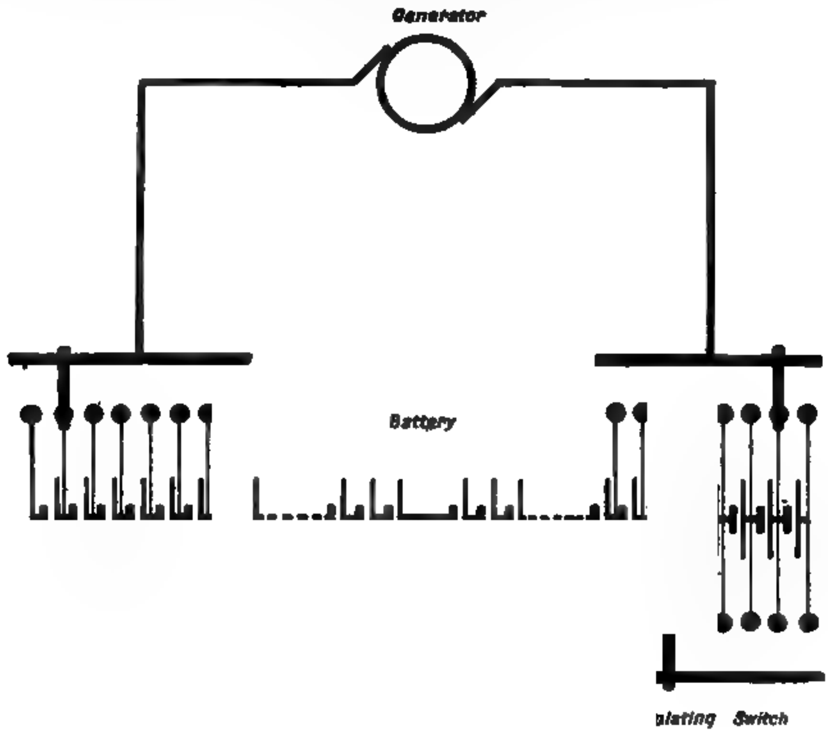


FIG. 116.—Battery used as balancer on three-wire network with regulating cells.

name of 'booster' is given. This consists of a motor generator having its primary connected to the omnibus bars or network and its secondary in series with the battery so as to add to the pressure of the mains.

The booster may be arranged in various ways; in all cases, it is required

that the secondary should give a considerable range of pressure. This may be accomplished by means of an ordinary fixed ratio motor generator of which the secondary pressure is varied by means of a resistance inserted in the armature circuit on the primary side. The method is a wasteful one, and its use is chiefly confined to small batteries. A very suitable arrangement is a variable ratio motor generator in which the secondary armature revolves in a field having an auxiliary magnet, the pressure being varied by altering the field strength. When a very large amount of variation is necessary, a motor and dynamo coupled together mechanically are employed and the fields of both varied.

The booster is so connected that the secondary armature is in series with the ordinary mains; it is, therefore, evident that only a small proportion of the energy put into the battery is transformed, so that, on the whole, there is not much loss by raising the pressure in this way.

The difficulties met with in consequence of the unequal amount of work on the regulating cells have brought about a tendency to dispense with their use. In traction work, the commonest way of connecting up the battery is to join it simply across the circuit and to use a plain shunt-wound machine as a generator. When the load is normal, the battery will be charged; but on any sudden access of load, the pressure from the machine will fall slightly, and the cells will then discharge into the line. Some makes of cell are better suited to this purpose than others; the smaller the difference between the pressure they require to charge them and their discharging pressure the better.

For lighting, the arrangement hardly gives sufficient regulation of pressure. It would probably be better to arrange to discharge the battery as a whole, and make up for its fall in pressure during working by means of a booster.

Incidentally, the variation of the pressure by steps of two volts is objectionable, and if, as is often the case, several cells are placed between each pair of contacts of the regulating switch, the effect on the light is most unpleasant.

In order to obtain a large variation in pressure by small steps, without having an undue number of contacts on the regulating switches and of connections to the battery, Messrs Verity & Co. have recently introduced a combination of two switches geared together, one of which alters the number of cells by steps of four, or other desired number, while the other varies the number one at a time.

To examine the working, suppose twenty different pressures are required. One switch has five contacts, to which four groups, each of four cells, are connected, while the other has four contacts, to which three single cells are connected. The arrangement is shown diagrammatically in fig. 117. The switches are so geared that the five-contact one moves forward one step for each complete revolution of the other.

The five-contact switch, which is actually circular, though shown developed in the diagram, has two distinct arms, insulated from one another, each with its own contact ring, but both passing over the same row of contacts. By this ingenious arrangement, the contact is always broken while no current is passing, hence avoiding all trouble from the slow motion imparted by the gear. The four-contact switch is provided with the ordinary arrangement of resistance for bridging across two adjacent contacts, already explained.

In the position shown in the figure, the last single cell is in circuit, and contact y is making connection to the second group of four cells. The next movement will cut out the single cell, leaving the four connected through x. Contact y then carries no current, and, as the motion continues, breaks connection with the first four cells, and next makes connection with the next

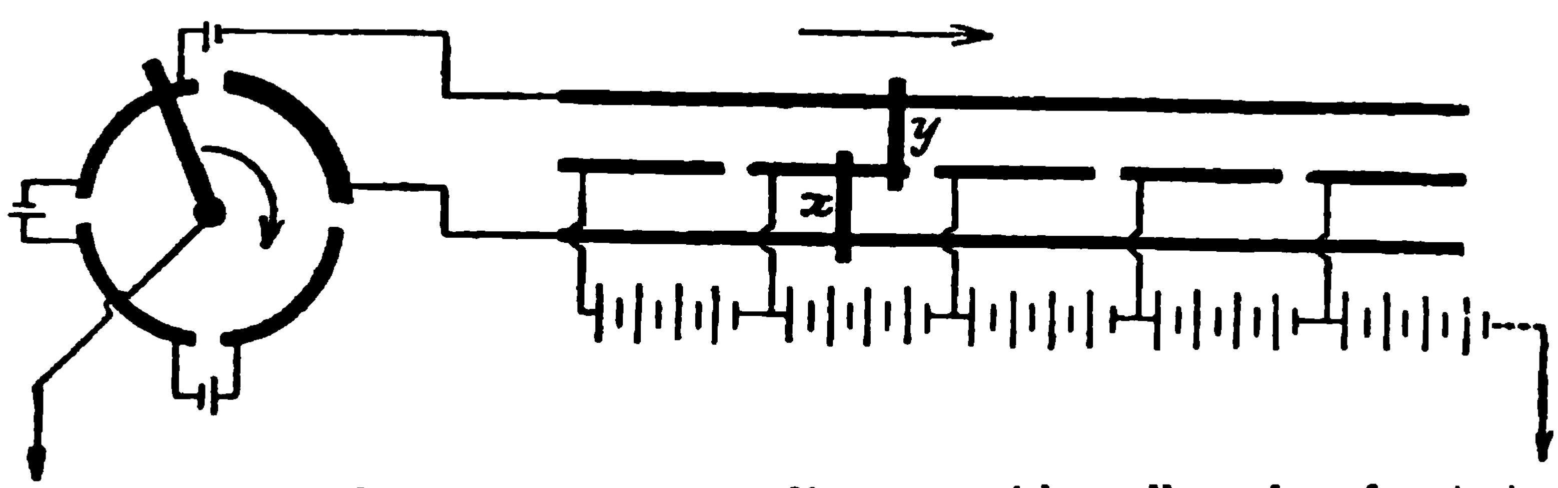


FIG. 117.—Special switches giving fine adjustment with small number of contacts.

group of four. The continued motion then causes connection to be broken with the ring connected with x, and y again comes into use, the three cells on the four-contact switch being in series with the group. These are cut out one by one, and the whole cycle is then repeated.

Another interesting battery switch invented by the late Dr John Hopkinson for automatically controlling the regulating cells may be referred to here. There are two varieties of the apparatus: one is employed for charging the battery, automatically cutting out the regulating cells as they become charged, the other for maintaining a constant pressure at any desired point.

To maintain constant pressure, the following arrangements are adopted: The switch that actually varies the number of cells differs only in detail from the ordinary type that is operated by hand, the resistance employed for bridging the contacts taking the form of lead plates in water and being connected between two concentric rings, one that on which the main arm bears, the other in connection with the subsidiary arm.

The switch is actuated by a motor geared to it. This motor has its field excited from a single cell, usually the end one, the armature by four or five cells, the direction of the current through it being determined by the controlling mechanism. This comprises a relay and a 're-setting' drum. The relay consists of two magnets, each of which has an armature contained in a brass box; one armature rests normally on the bottom, being kept down

by gravity; the other on the top, in virtue of the magnetic attraction. In their normal positions the circuits operated by the armatures are open.

The windings of the relays, each with an extra resistance in series with it, are connected in parallel between the two points between which constant pressure is to be maintained, the extra resistance of one relay intervening between it and one point, that of the other between it and the other point.

The resetting drum, of ebonite, carries contact-making surfaces which alter the connections of three brushes, so arranged that as the drum moves to one or other side of its normal position it either short-circuits the magnet of one relay or increases the current in that of the other.

When the standard pressure exists, the relay armatures are in their normal positions. Suppose the pressure to fall, the armature that is normally held up drops and allows current to pass through the motor, at the same time releasing a brake disc controlling a train of wheels connected with the switch. The motor revolves in such a sense as to add cells to the circuit, thus raising the pressure. When the switch has moved on one contact the resetting drum increases the strength of the relay, as already explained, and breaks the motor circuit. A special device causes the brake to stop the motor at the exact instant that the switch arm is centrally situated on the contact. If the pressure be too high, the other relay acts and operates the motor in the opposite direction, so as to take cells out of circuit. It is reset by the drum, which of course moves in the opposite direction. The form of relay adopted gives very firm contact and the switch works well.

The switch when applied to automatically cutting out regulating cells as they become charged is similar in general design, but necessarily differs somewhat in arrangement. The series of operations need not be described in detail.

In designing a battery sub-station, it is as important to arrange that everything shall be fire-resisting as in every other kind of building in connection with central station work. Furthermore, great care must be taken to use only such materials as are not greatly affected by acids, because the amount of acid spray given off during charging is considerable.

The floors and so much of the walls as is near enough to be splashed by the spray should be covered with asphalte. A thoroughly efficient system of ventilation should be provided, the plenum system being used in order to avoid the acid-laden air passing through the fans. A plentiful supply of water for swilling down the floors and for washing out the cells during repair is necessary, the drain pipes being laid with a view to their carrying off acid.

Conductors should be of bare metal supported on porcelain, all metallic objects being painted with acid-resisting paint or enamel. Where bare conductors cannot be used, the cables should be lead covered throughout their length. Switchboards and boosters should be kept in a separate chamber from the cells.

A large battery sub-station, designed by the Author in accordance with the principles just enunciated, will serve as an illustration of this class of work.

The battery is placed about a mile away from the generating station, and is fed from the ordinary distributing network, a five-wire one, into which it also discharges.

The method of charging adopted is by means of a separate motor mechanically coupled to a dynamo. Regulating cells are used to vary the pressure on the mains during discharge. Three intermediate points in the battery are connected to the mains.

The battery consists of 224 cells, each having a capacity of 1500 ampere hours and a maximum discharge rate of 600 amperes. These are divided into four groups of forty-four cells each, forming four main sub-batteries, A, B, C, and D, and four groups of twelve each, forming the regulating cells for A, B, C, and D respectively. The four sub-batteries, each of which has its own regulating cells, are always connected in series, but they can be arranged in any order, so that any one can be discharged into any one of the four pairs of mains forming the five-wire network.

The motor-driven generator will give any pressure up to 180 volts, and is connected in series with the 400 volts pressure given by the mains, giving 580 volts together for charging the whole of the cells in series. If one of the sub-batteries require considerably more charging than the remainder, it can be charged by itself, the whole of the current being then transformed by the booster.

The switchboard is of the open skeleton type advocated in Chapter XVII. It is shown diagrammatically in fig. 118, and a perspective view is given in fig. 119. There are seven vertical bars, four being connected through single pole switches to four of the conductors of the five-wire network, the next two through a two-way switch by means of which either one or the other, but not both simultaneously, can be connected to the remaining conductor of the network. One of these two bars, the sixth from the end, is connected to one pole of the generator side of the booster, and the seventh bar to its other pole, a double pole switch being inserted between the machines and the bars.

There are eight horizontal bars crossing these vertical bars, forming four pairs. One bar of each pair is connected to one pole of a sub-battery; the other is prolonged to form the regulating switch for the same sub-battery.

The regulating switches consist each of a flat bar; parallel with this is a series of twenty-five contacts, the end ones being broad, the remainder alternately narrow and broad. The broad contact nearest the main board is connected to the end of the sub-battery and to the first regulating cell, the remaining broad ones to the junctions between successive regulating cells. The narrow contacts are connected through a resistance, each to the next broad

FIG. 118.—Diagram of connections of Battery Sub-station for five-wire network.

contact, the object being, as with the more usual divided brush, to prevent the circuit being opened or a cell short-circuited as the switch passes from one

FIG. 119.—Battery Switchboard.

cell to the next. A laminated brush, moved by means of a long screw and hand-wheel, enables any contact to be connected with the bar.

By means of these switches, any number of the twelve regulating cells

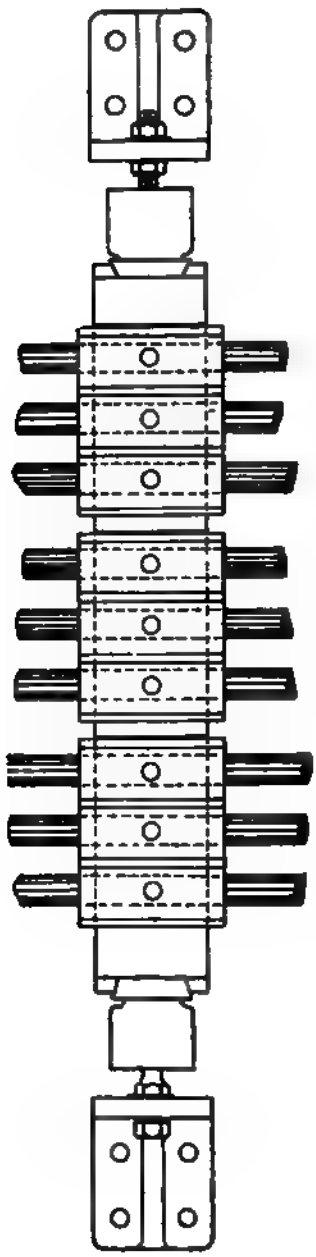


FIG. 120.—Method of carrying bare copper rods.

can be connected in series with the corresponding sub-battery before the main board is reached. By means of screwed plugs with collars, any horizontal bar can be connected to any vertical.

For discharging, the two-way switch is put over to the fifth bar, and the sub-batteries plugged on to the distributing mains in the desired order, the four single-pole switches being closed. By means of the regulating switches the pressure on each pair of mains can be independently varied.

For charging, the two-way switch is put over to the sixth bar, the three single-pole switches on the intermediate wires put off and the remaining one left on. The cells are thus left in series, and the motor-driven generator being run up, the added pressure supplied by it is available for charging, the

FIG. 121.—Diagram of Regulating Switch.

plug connecting the end cell having previously been transferred to the seventh bar.

The connections are made by means of solid round bare copper rods, supported on porcelain insulators, those joining up the sub-batteries being provided with oil insulators, those attached to the regulating cells being insulated from one another by porcelain insulators carried in a cast iron frame which is itself insulated from earth, as shown in fig. 120. The rods to the regulating cells are of smaller sectional area than those to the sub-batteries, because they are in use for a much shorter time, and the waste of energy in them is of less importance than the capital expenditure on the copper.

The resistances between the cells are conveniently arranged in the form of straight iron bars about four feet long, as shown in fig. 121.

The instruments comprise four ammeters reading up to 700 amperes in one direction for the discharge, and 400 amperes for the charge. These are

FIG. 122.—Instrument board for Battery Sub-station.

of the moving coil type, connected across conductors of known resistance. Four voltmeters reading up to 150 volts, each connected by a two-way switch

either to the mains or to a pair of the vertical bars of the switchboard; one voltmeter reading to 200 volts connected to the booster; and another reading to 600 volts connected across the outermost bars of the switchboard. These are all mounted on a cast iron frame, as shown in fig. 122.

In addition to these, four Aron ampere-hour meters with a double set of dials show the quantity put in and taken out of the battery.

The cells are mounted in some cases in a single row and in others in two tiers, cast iron frames with wrought iron girders being used to support the upper one. The cells are insulated with glass insulators and oil, and are kept clear of the floor.

CHAPTER XXVIII.

STREET LIGHTING.

THE access of a street lighting load to a central station is a matter of considerable importance, for the reason that the hours it endures are very considerable, amounting, for at all events a large proportion of the lamps, to some 4600 hours per annum, and a large part of the consumption takes place during the hours when the normal load is lightest. In a large town, the aggregate consumption for street lighting purposes reaches a very large amount.

There are two distinct problems involved in street lighting, viz.: (1) the kind of lamp to be employed, and the disposition of the various sources of light; and (2) the method of supplying these lamps with energy.

The efficient illumination of a street is by no means a simple matter, and there are a number of considerations to be taken into account. The objects of providing artificial light in a street are (*a*) To illuminate the surface of the footpaths and roadway, so that passengers can see any obstruction there may be; (*b*) To light up objects above the surface, so that vehicles and foot passengers can be clearly seen. The illumination should be as uniform as possible, and it is important that there should be an absence of glare.

It is a remarkable fact that a well-lighted street, judged by the above criteria, will often appear to a casual observer to be inferior to one in which the illumination is not nearly so good. There is a great tendency on the part of the public to judge of the lighting by the brightness of the lamps. For example, a street lighted by Welsbach gas burners appears to be very bright on account of the glare from the burners, but if the eye be cast upon the ground, it will be seen that it is quite dark. Similarly, the apparent lighting of a street by incandescent electric lamps will be greatly increased by placing a curved white reflector behind them, although the actual improvement is very slight. So marked is the effect that the appliance has been nicknamed an 'eye-cheater.'

The illumination afforded by a given number of lamps, disposed in a certain manner, will depend largely on the nature of the reflecting surfaces near them. If the roads be chalky and the buildings white, and not far

away from the lamps, the brilliancy will be enormously greater than if the roads be paved with dull, muddy, granite setts, and the buildings be begrimed with smoke, and practically as absorbent of light as lampblack. This influence of surrounding objects must not be overlooked in determining the arrangement of lamps; if it is, the results based upon experience in other towns, where the conditions are more favourable, may be most disappointing.

Uniformity of illumination of a surface depends upon every unit of area of that surface being as nearly as possible the same distance from the source of the light. This, therefore, obviously points to having the lamps placed as high as possible, and, if the intensity of the illumination is to be great, the lamps must be of very large power. In this manner, requisite (*a*) just mentioned can be fulfilled. On the other hand, this arrangement is entirely incompatible with condition (*b*), since the rays being nearly vertical, they hardly illuminate vertical objects at all.

The best way to combine both desiderata is to have a number of lamps of moderate power placed fairly close together, and fixed at no great height.

Two most excellent examples of the two systems, each the best in its way that is known to the Author, may be cited: (*a*) In Brussels, the Grande Place, an open square or market-place of very large extent, is illuminated by only two arc lamps of great power slung up on span wires suspended across the square from the buildings on opposite sides, the lamps being but little below the roof level, which is at a very considerable elevation, as the buildings are high. The effect is that of moonlight, and in conjunction with the surroundings, which are of great beauty, is most pleasing. On the other hand, there are but few situations in which the same treatment could be repeated without complete disappointment.

(*b*) Paris furnishes the example of the second system. In the Avenue de l'Opéra, a broad thoroughfare, with tall buildings on either side, the lamps are in three lines; one is formed by fairly tall posts along the middle line of the street, about one hundred yards apart; the others by substantially lower posts fixed about thirty yards apart along the kerbs. The effect is magnificent, though the outlay must be lavish,—amounting to prodigality.

The first point to consider is the kind of lamp to be employed. This will necessarily be influenced by the amount of illumination desired. It is generally found that a very much higher standard is expected by the public from electric lighting than from gas or oil, and unless this is provided, dissatisfaction and disappointment are certain to ensue.

In side streets, incandescent lamps have been used with satisfactory results where surrounding conditions are favourable, and in streets in which it is merely desired to replace gas without improving the lighting, or where a high standard of illumination is not necessary, they may be recommended.

On the whole, however, arc lamps are greatly to be preferred, and in important streets are imperative.

Arc lamps, even now, though so largely used, are far from perfect, and it cannot be denied that they entail a considerable amount of labour, trouble, and skill in maintenance. Much of this might be removed if manufacturers could be induced to realise the conditions under which lamps have to work when placed on the top of a high post exposed to strong winds and all weathers, conditions very different to those in the interior of a building. For example, it is a matter of the utmost difficulty to obtain lamps insulated on both poles, the whole framework usually forming part of the circuit, and the lamp being hung from a ring of porcelain, giving but little insulation from the pillar, which necessarily makes exceedingly good earth. Furthermore, the lamp is in great danger of swinging into actual contact with the pillar. Such insulation as there is on the other pole is often very meagre, little scraps of mica, giving no surface resistance, being often thought good enough. Again, many lamps are most complicated and flimsily made, requiring care in adjustment. How much delicacy of touch or minute attention can be expected from a lamp trimmer hanging for dear life to the top of a pole in a gale of wind? Could anything be more out of place than a silk cord in a street lamp, or a number of toothed clock wheels among the dust and dirt of traffic?

Arc lamps are attended with a good deal of inconvenience in the shape of accessories, such as line resistances, automatic cutouts, and substitutional resistances; these are bulky, and space for their accommodation is very scarce, while each introduces an element of risk of breakdown.

The invention of the Nernst lamp gave promise of an efficient substitute for arc lamps in all streets except those of the first importance, and one free from most of their drawbacks. So far the promises held out at its first announcement do not appear to be in the way of being realised, but if whatever difficulties there may be that hinder its development be overcome, it should go far towards solving the question of satisfactory street lighting.

Street lighting, however, has to be done now without waiting for possible ideal apparatus, and arc lamps must be taken as they are, with all their faults. The first point to settle is their disposition in the street. If they be placed along the edge of the footpath, it is obvious that the light will be much more intense on the path than on the roadway, while a large proportion of the rays will impinge upon the buildings. If these be white and well reflecting, they will return the greater part of the light in a very fairly well diffused and useful form, and they will be rather useful than otherwise; but if the surfaces be of an absorbent character, they will give back practically nothing, and much of the light will be wasted.

The chance of being able to utilise all the light of the lamps is greatly increased by placing the lamps in the middle of the roadway, as the

buildings will then be too far away in most cases to greatly affect the result, though good reflecting surfaces are still useful in increasing the light on the footpaths. This system undoubtedly gives a higher intensity in the roadway than on the footpaths, and it is a moot point whether this or its opposite is to be desired. On the whole, it would seem that the better light is required for vehicular traffic, supposing that a really good light is given, enabling approaching vehicles to be clearly seen, otherwise the light may do more harm than good by making the lamps carried by the vehicles less conspicuous. This point is apparently lost sight of by those gasophiles who ridicule the placing of electric lamps in the middle of the streets, stating that the experience gained with gas points to the desirability of the bulk of the light being brought to bear on the pathway. They apparently forget that a gas-lit street is one in which but little can be seen.

The lamps for central lighting may be supported on posts in the middle of the roadway. This is particularly appropriate when routes along which electric trams run are being dealt with, if the centre pole system of overhead traction be adopted, while it may be employed with advantage when trams are absent if the thoroughfare to be lighted be broad. In narrow streets, however, centre poles are a great obstruction to traffic, for, in spite of the contention that they regulate the flow by dividing it into two clearly defined channels, they undoubtedly to a serious extent prevent rapidly moving vehicles passing slow ones.

The method of suspending the centre lamps from span wires passing from building to building is largely used abroad and to a slight extent in this country, notably in Liverpool, and has much to recommend it. It dispenses altogether with posts, whether in the roadway or footpath, and the vast improvement of the street in appearance and convenience must be seen to be appreciated. The two drawbacks, however, are the difficulty of getting permission from the owners or occupiers of property for the necessary attachments to be made to the buildings, and the difficulty of trimming the lamps. In some cases the lamp is lowered as indicated diagrammatically in fig. 123; in others it is pulled to the side for trimming; lastly, it may be trimmed in position when traffic is slack. The conductors for the lamp somewhat detract from the appearance of the suspension, but this is a small matter.

If lamps be fixed at the side of the road, they should be arranged to be as far as possible from the buildings, and with this end in view a curved arm, drooping from the post towards the middle of the road, may be used with advantage.

The way in which the lamp is fixed is a matter of some importance. It may be suspended and be allowed to hang free, in which case it is much exposed to the weather, or it may be placed beneath a hood which affords a considerable amount of shelter, or, lastly, it may be enclosed within a

lantern. This last method is undoubtedly the best for the lamp, as it is shielded from many deteriorating influences, but the appearance is seldom so good as the free lamp, and there is a tendency to obscure too much light with the lantern itself.

On account of the variations of the local conditions already pointed out and the standard of illumination required, it is impossible to lay down any general rule either as to the power of the lamps, their height, or their distance apart.

The most usual capacity is about 500 to 600 watts, alternating lamps being used of rather larger capacity than continuous, on account of their

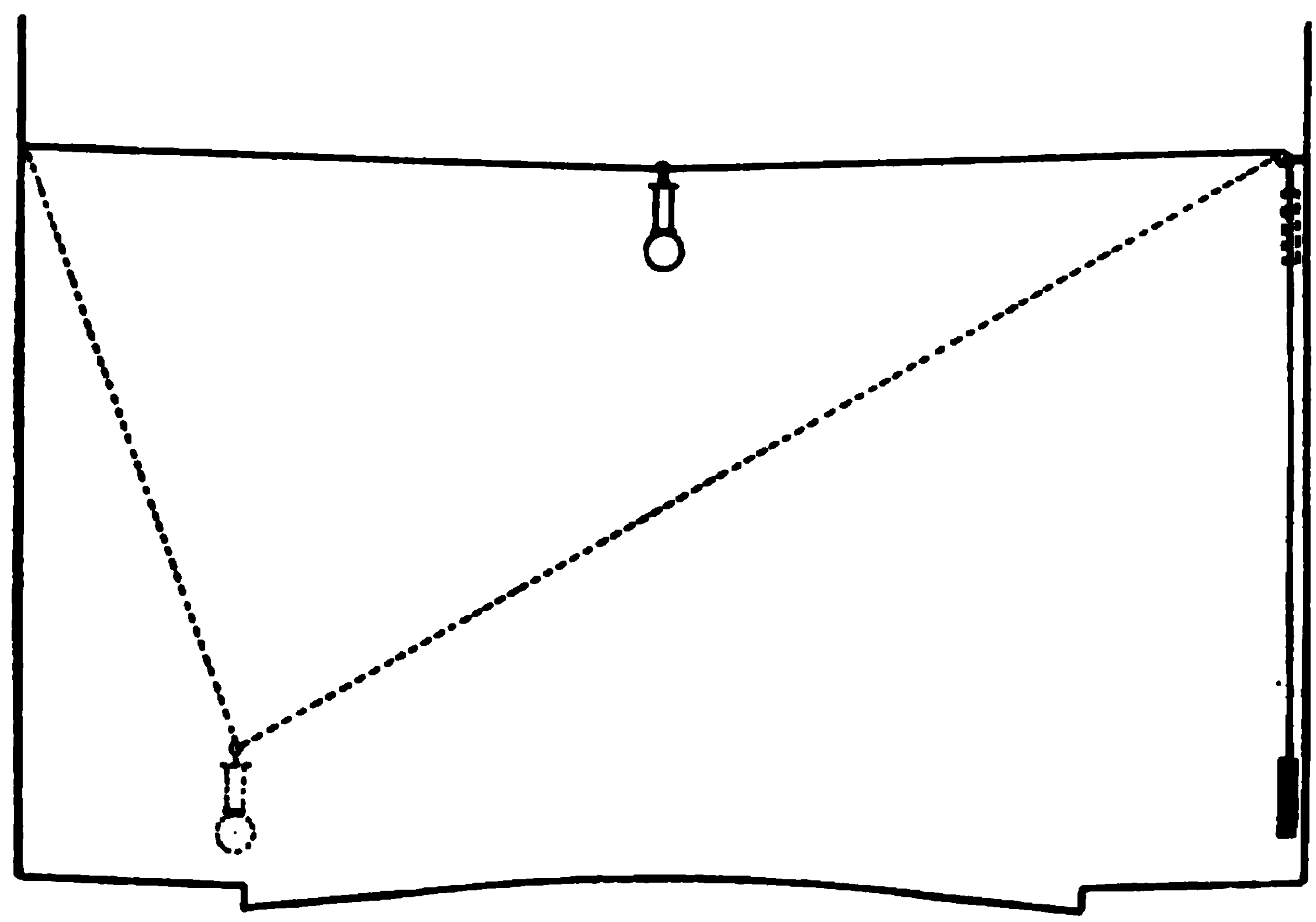


FIG. 123.—Method of lowering lamp for trimming when suspended from a span wire.

lower efficiency. Lamps taking as much as 750 watts are occasionally used, but are the exception.

The height from the ground is also very variable: the most usual is, perhaps, 22 feet, but 18 feet gives good results if the lamps are close together, while, if far apart, they may be 26 and even 30 feet high.

The distance apart of the lamps varies greatly. They are seldom placed closer than 40 yards, and not infrequently are as much as 100 yards apart, though this distance is occasionally exceeded.

Arc lamps may be fed with alternating, rectified, or continuous current, and with any of the three the arc may be either open or enclosed.

The difference between arcs fed with the three classes of current lies principally in the distribution of light from the carbons. Continuous current arcs indisputably give the best distribution of light, and are the most efficient, rectified currents giving practically the same results, with the

added advantage that the vibration attendant on this class of current tends to keep the mechanism of the lamp free and smoothly working. Alternating current arcs, in spite of their low efficiency and manifest disadvantages, have in a few cases been used with a large measure of success, but this is quite the exception, and continuous current lamps should in all cases be provided.

The relative merits of enclosed and open arc lamps demand careful consideration, and local considerations will to some extent determine the choice. In the first place, the mechanism of enclosed arc lamps is substantially more simple than that of open ones, and as a corollary they are of neater appearance. The consumption of carbon is very much less, being not much more than one-tenth. In consequence of the slow combustion, much less attention is required for trimming, and the necessary number of hours' interval between two trimmings is attained without the introduction of the double lamp with automatic switching-over mechanism, as is practically indispensable with open arcs. Owing to the lamp taking double pressure across its terminals, it is possible to use single lamps instead of pairs, with a pressure of distribution of 100 volts and even higher; this is an immense advantage, and in some cases is alone sufficient to turn the scale in their favour. Against these advantages must be set the fact that, although the distribution of light is probably better with the enclosed than with the open arc, the efficiency is almost certainly less. In consequence of this, and probably on account also of the different distribution of the light making the brightness appear less than it really is, enclosed lamps have been used sparingly for street lighting, though for the lighting of interiors the demand for them has been great.

It would be foreign to the intention of this book to enter into the details of the mechanism of arc lamps: they must be sought in works devoted to the subject. Lamps exist in almost endless variety, but those that can be really trusted for street lighting are few in number.

The type selected should be as simple as possible, and the lamps should be arranged to burn in series across the mains, the number depending, of course, on the pressure maintained. Each lamp should be provided with an automatic cutout, to cut it out of circuit in case of failure and switch in an equivalent or "substitutional resistance." This cutout is more convenient if entirely independent of the lamp, as it can in that case be fixed in the base of the post together with the resistance and only two wires need then be run up to the lamp. The lamp, unless of the enclosed type, should have two pairs of carbons, each sufficient for 16 hours, or 32 hours in all, when trimmed with carbons of full length, the lamps changing over automatically to the second pair when the first is consumed. Apart from the convenience of the increased period of time that the double carbon lamp will run without retrimming, it has the great advantage that the short ends of carbon left after

trimming can be used up. For 10 ampere lamps, the most suitable size of carbons is 18 mms. and 12 mms., and with these diameters they may be of equal length. Great care should be taken to secure carbons of the very best quality, as otherwise the best of lamps will give unsatisfactory results. As already stated, the lamps should be insulated thoroughly well on both poles.

The accessories of arc lamps give a good deal of trouble. The resistances rapidly deteriorate, especially if of German silver or similar alloy. One of the most satisfactory materials in the Author's experience is that known as "Beacon" wire, which is an iron alloy that does not appear to have much tendency to rust and has a high specific resistance. The Author has proposed, but has not actually tried, incandescent lamps for substitutional resistances. They would be compact, unaffected by the weather, and by lighting up when the arc lamp was cut out would make some compensation for the loss of its illumination. As the substitutional resistances only rarely come into operation, the lamps ought to last a very long time.

The switches used for turning the lamps on and off should be of massive construction, and may with advantage be enclosed in watertight cases, the handle projecting through the case.

When the lamps form part of a high pressure circuit, a switch should be provided to isolate each lamp, and no person should on any account be allowed to handle the lamp unless it be cut off completely from the circuit. The Board of Trade require each post, when high pressure is used, to be connected to earth, and this useful provision should be effectually carried out.

In many towns, it is the custom to reduce the illumination after a certain hour. As arc lamps cannot well be adjusted to burn at two different rates, and as the provision of two sets of lamps would be costly and inconvenient, the expedient is often adopted of changing over to one or two incandescent lamps on each post when the hour is reached for reducing the amount of light.

In the Author's opinion, a far better practice is to extinguish alternate arc lamps, leaving the remainder burning. The effect is incomparably better and the cost for energy is not very different, for each arc lamp, as usually arranged, represents not more than four 32 candle lamps, and in a street of any importance, less than two such lamps could hardly be substituted for the arc. These, therefore, consume energy at just half the rate of the arc lamp, so that the total consumption in a given time would be the same whether two 32 candle lamps were substituted for every arc lamp or alternate arcs were extinguished. If smaller power incandescent lamps were used, there would, of course, be a saving in energy, but it hardly seems worth while to attach much importance to this, as the cost of production for such a long-hour load is low and the effect of the arc lamps incomparably better than that of incandescent.

We have now to turn to the problem of the best means of supplying the lamps with energy. There are two courses open, viz., (1) to supply them from the ordinary distributing mains, or (2) from special circuits for street lighting only. If the former course be adopted, the lamps must necessarily be supplied with the same kind of current as are ordinary consumers, whereas, if distinct circuits be used, the choice is unrestricted.

The advantages of using the ordinary mains are very great. In the first place, the current occupies only a small proportion of a heavy main, and the cost for conductors is therefore very much less than if a separate system be laid down. Secondly, the supply is available in every street in which distributing mains are laid, and hence isolated portions of streets can be electrically lighted with profit, which would not pay if special mains had to be run. Thirdly, the energy used is produced at the lowest possible rate, being derived from the main generators, while the cost of distribution does not involve any special charges. Fourthly, the risk of breakdown is much less, since the lamps are divided into a large number of small groups. Lastly, the supply is at low pressure and is thus perfectly safe. Practically the only drawback is that the lamps cannot be controlled from the generating or transforming station, and must be turned off and on from a number of points. This, however, is a trifling matter compared with the whole cost.

If the separate system be adopted, it is practically essential that a large number should be run in series, and be supplied at high pressure, because the distances to be covered are usually considerable, and the arrangement has the merit of simplicity.

The lamps may either be supplied from the main generators, unless they be low pressure machines, or from entirely separate machines. The former course is by far the better, for, if separate plant has to be put down, one of the main advantages of street lighting from the producer's point of view is lost, since the hours of user of the ordinary generators are not increased, but, on the contrary, entirely separate plant has to be put down, and must be kept idle throughout the hours of daylight. Moreover, the generators are, of necessity, small, and are therefore of lower efficiency than the main machines, costing also much more in proportion for attendance and repairs.

Assuming the main generators to be used, the following courses are open, viz.: (1) If the supply be continuous current at high pressure, the supply can be given directly from the station omnibus bars, the lamps being divided up into circuits with a number on each appropriate to the pressure, all the circuits being connected up in parallel with one another. The arrangement provides for very satisfactory lighting, and is probably the best of the separate systems, but it does not tend to facilitate the running of the ordinary high pressure feeders, on account of the great liability to the development of earths on the lamps.

(2) If the supply be an alternating one at high pressure, the lamps may be run in series, as in the last case, but this is not satisfactory.

(3) With high pressure alternating supply, there is another method, consisting in supplying each lamp from a separate transformer, the secondary of which gives the pressure required by the lamp, the primaries of all being connected in parallel. Although the capital outlay involved is considerable, the results are very satisfactory, and the elimination of the lamps from direct connection with the high pressure circuits is a great gain. The lamps, of course, are less efficient than with continuous current.

(4) Yet a third course is open when high pressure alternating current is generated. This consists in converting the current into a unidirectional one by means of rectifiers. This apparatus consists of a static transformer giving constant current, and a commutator driven by a synchronous motor. It is said to have a high efficiency, varying from 93 per cent. at full load, to 87·4 per cent. at half load. There is, however, a considerable amount of difficulty in running the machines, as they are apt to go out of step, and the current to flash over the surface of the commutator. When thoroughly understood and properly managed, however, they are said to give excellent results. The lamps supplied with rectified current give results equivalent to those with ordinary direct current, and the slight jar from the intermittent impulses is very conducive to the smooth and even working of the mechanism.

(5) Although, when the separate system is used with low pressure generation, the lamps cannot well be supplied directly from the station, yet they may be supplied through the intervention of a motor generator transforming up to the desired pressure. This, though somewhat inefficient, may be preferable to employing separate generating plant.

If it be decided to adopt separate generating plant, the machines will, of course, be high pressure continuous current ones, and each one will either supply a single circuit containing a considerable number of lamps, or several such circuits arranged in parallel on the machine. The latter course has much to recommend it, as it enables generators of larger size to be used, and this improves the efficiency of the arrangement.

Reference must not be omitted to the trimming of arc lamps. There can be no question that an arrangement for lowering them would be by far the best plan, as the attendant could then stand on the ground and give his undivided attention to the lamp, to all parts of which he would have complete and easy access, but, although several devices possessing considerable merit have been brought out, none has met with any degree of general favour. The difficulty consists in designing an appliance that shall be at once cheap, reliable, of a sightly appearance, shall ensure good contact for the lamp terminals, and that shall be free from all danger of allowing the lamp to drop accidentally.

Tower ladders may be employed for giving access to the lamps in position, but they are very cumbersome, inconvenient, and liable to rapid deterioration.

An ordinary ladder placed against the lamp-post is probably as good as anything, the attendant supporting himself on a sling at the top of the post while he is attending to the lamp.

In some cases holes are provided in the posts in which stepping irons can be placed, and one invention consists in a number of sliding pegs which can be slid out to form footholds. Both these methods are objectionable, being inconvenient, and none too safe for the attendant; while the holes in the post allow water to gain access to the interior. A further disadvantage consists in the damage done to the paint on the post by the men's feet when climbing.

There are a number of details in street lighting, which cannot be gone into here. Two, however, may be mentioned. The appearance of the light depends greatly upon the globe used. Naked arcs give a most unpleasant glare, and some medium should be, and practically always is, used to temper the light; on the other hand, the other extreme of choking off half the illumination cannot be too strongly condemned. Slightly clouded opal globes with a crinkled surface give excellent results. Thick glass plates with roughened surface are wasteful, and to some tastes unpleasing. One of the best globes the Author has seen is in use in Paris. It is divided vertically into two hemispheres; each is fixed in a brass band, and these bands are hinged together. The joint is in the same plane as the arms supporting the canopy of the lamp, so that no extra shadow is cast. By opening the globe the lamp is easily reached for retrimming, without any necessity for moving or sliding away the glass.

The second point of detail is the question of painting the posts. A system has recently been introduced of coating them with aluminium, by first varnishing them all over, and then applying aluminium in the form of a very fine dust, by means of an air blast. When new, the appearance is very good indeed, but time alone can show whether it be durable. Probably in clean inland towns it will last well, but near the sea, or in large manufacturing towns, its prospects are not good.

CHAPTER XXIX.

THE COST OF PRODUCTION.

THE cost of producing a given quantity of electrical energy varies enormously with the rate at which it is produced, and, to a large extent, with local conditions. In the case of a central station supplying many different classes of consumer, the average cost affords no clue to the actual cost of the energy supplied to each class, and it is, in fact, impossible, with the data so far available, to predetermine the cost of production in any particular town.

The real cost of production is an extremely complicated matter, but the broad principles which underlie the subject were clearly enunciated by the late Dr John Hopkinson in his Presidential Address to the Junior Engineering Society delivered in 1892. In this address it is shown that the cost is made up of two distinct parts, one a fixed or standing charge, dependent upon the maximum rate at which the energy may be demanded, and quite independent of the time over which this demand may extend,—that is to say, independent for a given demand of the total quantity of energy demanded; and secondly, a running charge proportional to the time the demand is kept up, or, in other words, to the total quantity demanded for a given maximum rate. In point of fact, one portion of the cost is for the being ready to run, the other for actually running. Dr Hopkinson very aptly takes as an analogy the case of a harbour: this costs a certain amount for interest on the capital expended on constructing it, and this is the same whether it be used much or little; so, too, the interest on the capital sunk in providing the generating plant is independent of the time for which it is run.

Let us now examine in detail what are the standing charges of a central station.

For every kilowatt of consuming devices installed, there must be provided a corresponding capacity of (1) boilers, together with their accessories of feed pumps, feed tanks, coal storage, coal conveying plant, mechanical stokers, steam pipes, etc.; (2) engines, with their condensers, pumps, condensing water tanks, spare parts, etc.; (3) dynamos; (4) switchgear and instruments; (5) land on which the plant may stand, which will involve an

annual charge for rates in addition to the interest on the purchase money; (6) buildings to house the plant, together with such accessories as cranes, etc.; (7) distributing mains and feeders, using the term in the broadest sense to include transformers or transforming stations; (8) service lines, meters, fuses, and accessories in consumers' installations. The capital expenditure on this plant involves annual charges for interest and for amortisation; the plant will require an annual sum for repairs, which will be the same for a portion, whether energy is being supplied or not; but for the remainder it will be rather heavier if the plant is supplying than if it is merely running light.

The items above enumerated are the more obvious components of the standing charges, but there are others equally important; these are (1) wages of men in boiler house, engine room, mains and installation departments; these men must be in attendance whether much or little plant is running, but the numbers employed in the engine room and boiler house will undoubtedly be increased with the amount of plant actually at work, so that a portion only of these wages must be regarded as a standing charge; (2) the amount of coal necessary to be burnt per hour to maintain the temperature of the boilers, steam pipes, engine jackets, etc.: this is a very heavy item, and will amount to about 14 lbs. of coal per day per kilowatt of capacity of plant; (3) office accommodation, clerical staff, and "establishment charges"; (4) salaries of engineering and managerial staff.

The various items enumerated are not actually proportional to the maximum demand in kilowatts; many of them tend to diminish per kilowatt as the size of the station increases, as will be more fully referred to later on, but they are all independent of the number of hours the demand is kept up. Again, the term 'cost of production' is used above in its widest sense; it is more usual to subdivide the cost into cost of generation and cost of distribution, and this may conveniently be done, but the two together are the true cost of supply.

The running charges must now be considered. (1) The most important is undoubtedly the coal that must be burnt to supply steam to the engines, as distinguished from that required to maintain the temperature against the radiation losses. This will not be strictly proportional to the output for a given maximum rate, as the steam consumption depends upon the load at which a particular engine is working, but by proper subdivision of the plant it can be made sensibly so. (2) Feed water; this is practically proportional to the coal burnt. (3) Oil, cotton waste, and engine room stores; these are roughly proportional to the time of running. (4) Wear and tear, causing repair and renewal of plant; this is practically proportional to the time of running, but perhaps increases at a slightly greater rate than simply in proportion. (5) Additional wages for men over and above those required for standing by the plant in readiness to run it. (6) Loss by leakage and

resistance in distributing mains, and transmission losses in feeders, including transformer losses. If transformers are left on, irrespective of the load, a portion of the loss in them is, of course, a standing expense.

In the address given by Dr Hopkinson, referred to above, he takes the concrete case of a station capable of supplying 2500 kilowatts, and estimates the cost of running light or being ready to run, and actually running fully loaded, to be, respectively, as follows (distribution costs being omitted):—

	Running Light.	Fully Loaded.
	£	£
Land,	1000	1000
Buildings,	1500	1500
Rates,	500	500
Boilers,	2100	2100
Switchboard and conductors,	7800	7800
Engines,	2160	3600
Dynamos,	1350	2250
Coal,	6000	30,000
Stores,	600	3000
Wages,	5000	7500
	28,010	59,250

These figures show that the standing charges, or the cost of being ready to supply, will not differ greatly from £11 per kilowatt, while the running charges, or cost of giving the supply, will not be much more than one-third of a penny per kilowatt hour. The following table shows various load factors from five per cent. to one hundred per cent., and the corresponding costs of production, including both standing and running charges based on these figures; the results are expressed graphically in fig. 124.

5 per cent.	6·36d.	55 per cent.	0·87d.
10 ,,	3·34d.	60 ,,	0·83d.
15 ,,	2·33d.	65 ,,	0·79d.
20 ,,	1·83d.	70 ,,	0·76d.
25 ,,	1·53d.	75 ,,	0·73d.
30 ,,	1·33d.	80 ,,	0·70d.
35 ,,	1·19d.	85 ,,	0·68d.
40 ,,	1·08d.	90 ,,	0·66d.
45 ,,	0·99d.	95 ,,	0·64d.
50 ,,	0·93d.	100 ,,	0·63d.

The figures given by Dr Hopkinson are arrived at from theoretical considerations, and take a broad view of the question; they may be open to correction in matters of detail, but their general accuracy has never been assailed. They are somewhat difficult to test by means of figures attained in actual practice, so far as relates to the relative magnitude of the two items of cost, since the value of the actual standing charges is hard to ascertain; it is probable, however, that the fixed are estimated on a somewhat liberal

scale, while the running charges are difficult to approach in practice. In a paper by Mr Arthur Wright in 1896, he states, as the result of careful analysis of figures relating to the central station at Brighton, that the standing charges there amount to about £18 per kilowatt, and the running charges to about three-fourths of a penny per kilowatt hour. Both these items of cost are greatly in excess of those arrived at by Dr Hopkinson, but they are of the same order of magnitude, actually and relatively, and go far to confirm his figures.

Subsequently Mr Wright found that in 1897, of the total revenue charges, 81 per cent. were for keeping machinery, staff, and mains in readiness for running, the remainder being for the extra cost of actual running, or rather over ½d per unit. He states that, for a demand extending over 365 hours

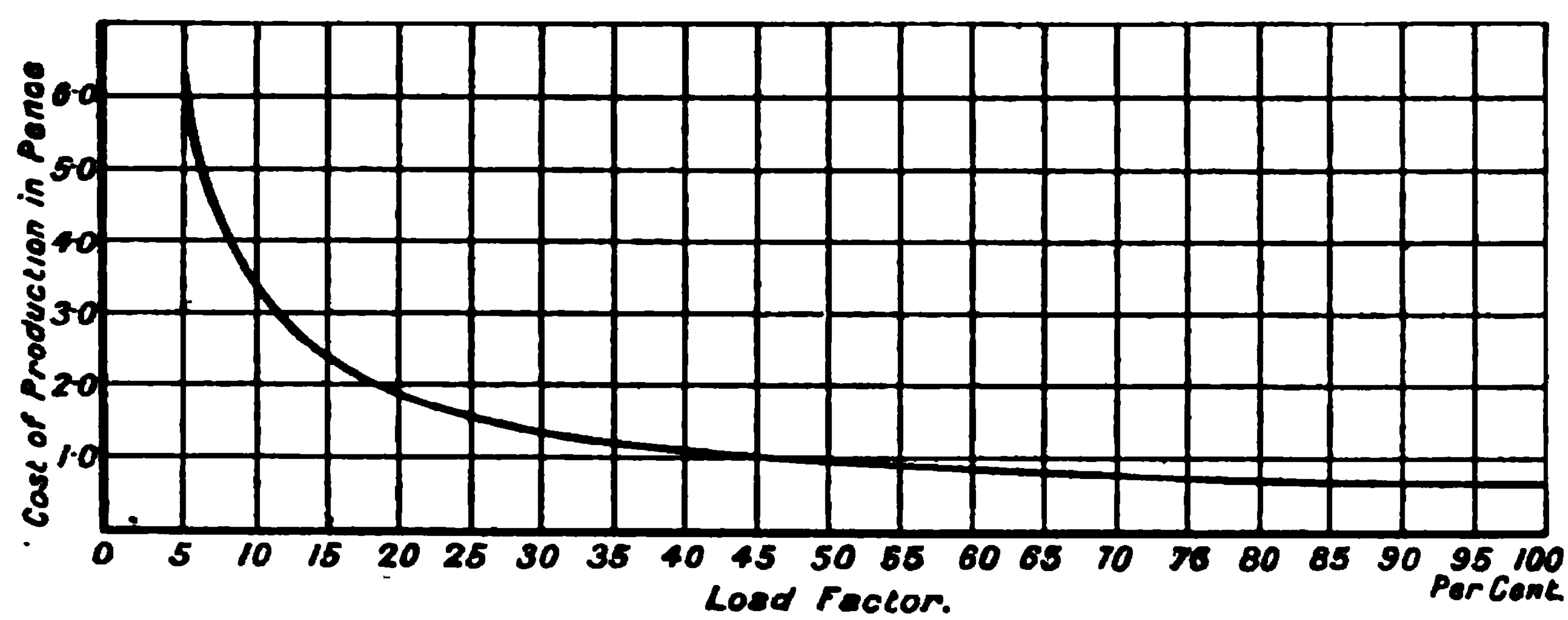


FIG. 124.—Curve showing relation between cost and load factor.

per annum, the actual cost is 7½d. per unit, which corresponds to £10, 13s. per kilowatt of maximum demand and ½d. per unit, which is a much closer approximation to Dr Hopkinson's estimate.

Now it will at once be evident that, since the standing charge is proportional to the number of kilowatts of maximum demand, and independent of the time that demand is in operation, while the running charges are directly proportional to the time, in other words, to the number of kilowatt-hours, the total cost per kilowatt-hour, averaged over the whole output, will diminish rapidly as the time, or length of user, increases. This length of user, considered in relation to the maximum demand, is usually denoted by the term 'load factor.' This expression is used with a number of different shades of meaning, but the earliest sense in which it was employed by Mr Crompton, who originated it, was defined by him to be "the relation which the actual output of a plant of any given size bears to what would be its output if it were worked continuously day and night at the full load for the same period."

No central station plant ever works at a 100 per cent. load factor, *i.e.* at its full rate for 24 hours per day, though electro-chemical plants often

do so, and the cost of production is then incredibly small. On the contrary, a 15 per cent. load factor may be looked upon as a good one. The daily load factor for a given station which has become well established, so that rapid access of consumers does not mask the normal conditions, varies with the season of the year and with the weather.

The load factor does not take account of the way in which the load varies from hour to hour; thus a 10 per cent. load factor might be produced by the whole plant being run for rather under 2½ hours per day, or by half the plant being run for somewhat less than five hours. This mode of variation of demand is shown by means of 'load curves.' These curves are plotted with the instantaneous values of the rate of output in kilowatts for ordinates, and the intervals of time from the beginning of the day as abscissæ. They show at a glance how the demand varies, and the integration of the area contained between the curve and its axes gives the total output in kilowatt-hours, and thus enables the load factor to be determined.

The load factor and the shape of the load curve depend on the nature of the demand supplied. In a purely residential neighbourhood there will be a very low load factor in summer, energy only being required at dusk, and, in the West End of London and the fashionable suburbs of the towns, none whatever may be wanted for several months, the houses being shut up. In the winter, there will be a demand from say 6 a.m. to 8 a.m., while rooms are being got ready and breakfast taken, and from dusk until 10, 11 or 12 p.m.

In business quarters there will be practically no light required in offices or in the better class of shops in the summer, and in the winter the load will go off at 5 or 6 o'clock. Shops in lower class neighbourhoods will require light for longer periods, as they remain open much longer.

Hotels and clubs give a higher load factor, lamps being often required all day in many parts of the premises, and light is required until very late, a number of lamps burning all night.

Motive power provides an excellent load factor, in some cases exceeding 30 per cent.

Now it is clear that the load curve of an actual station is made up of the curves of each of the districts catered for, superposed on each other, and, inasmuch as the time of the maximum load varies greatly according to the class of consumer, even though the load factor may be the same in each case, it may be that the load factor of the station may be much higher than that of any one of the individual districts. Thus, a station supplying a warehouse and first-class shop district will find its work practically done at 6 p.m., but, if a residential load be added, this will extend the load on to 10 p.m. or later. In the same manner, a motor load will fill up the period from early morning to dusk. Of course, these loads will not exactly fit into

one another, so as to give a steady load; at certain periods of the year they are bound to overlap and so send up the maximum rate at which the demand takes place, but, nevertheless, the load factor is improved.

The prime essential for low cost of production is, that the load should extend over a long period; for the standing charges, which are determined solely by the maximum rate of demand, are thus spread over a larger number of units. Thus, in the case of, say, a 10 per cent. load factor, the plant is only working at its full capacity for about 2½ hours per day. This means that the whole of the standing charges must be covered by the sale of a number of units, only one-tenth of the number that would be sold if the load factor were 100 per cent.; or, in other words, the proportion of the average cost per kilowatt hour, which is due to the standing charges, is ten times as great in the one case, as it would be in the other.

The item which is next in importance in contributing to low cost, is the time at which the demand takes place, *i.e.* the hours between which the energy is required. If this is such that there is no chance of one kind of demand overlapping another, the importance is immense, but, if this is not the case, the time of the demand is practically insignificant, for, if the two demands are liable to be superposed, even though it be once only in the year, say, for instance, in the case of a fog, plant must be provided to meet that demand, and the standing charges are consequently increased. Is there no good effect, then, by superposing a long-hour load on a short-hour load? Most certainly there is, for the effect is to raise the whole load curve bodily, and so diminish the ratio of the maximum rate of demand, or 'peak' of the curve as it is called, to the mean rate, in other words, to improve the load factor.

The foregoing remarks will make clear the fallacy of seeking after what is so often called a 'day-load'; it is not a day-load, but a long-hour load that is wanted; the time of the demand being of quite secondary importance. It would be far more in accord with the fitness of things if an 'all-night' load were sought; this could never overlap the day or evening load.

From what has been said, it will be seen that the serving of a large area may greatly lower the costs of production, by enabling a number of different classes of district to be tapped, and so improving the load factor. The possibility of reduction of cost depends, however, on the nature of the different districts, a fact that appears to be lost sight of in some of the large schemes that have been propounded from time to time. Where a large town, including within itself many different trading areas and the adjoining suburban districts, can be supplied from one centre, highly satisfactory results may be expected. It is difficult to see, however, what good effect can be looked for by the combination of a number of precisely similar towns, situated at great distances from one another. The load

curve of the large station will be practically the same as that of the station supplying any one of the towns, and the load factor will be unaltered.

No doubt there are substantial economies to be effected in a large station. A large station admits of the use of large units of plant. Large units are usually more efficient than a number of small ones, their first cost per kilowatt is less, the cost of attendance is much less, the cost of management is likewise diminished. In a large station, the scale of operations is such as to justify the introduction of labour-saving appliances. Against these economies, however, must be set the cost of the high pressure mains connecting the distant towns, and, in the case supposed, this is

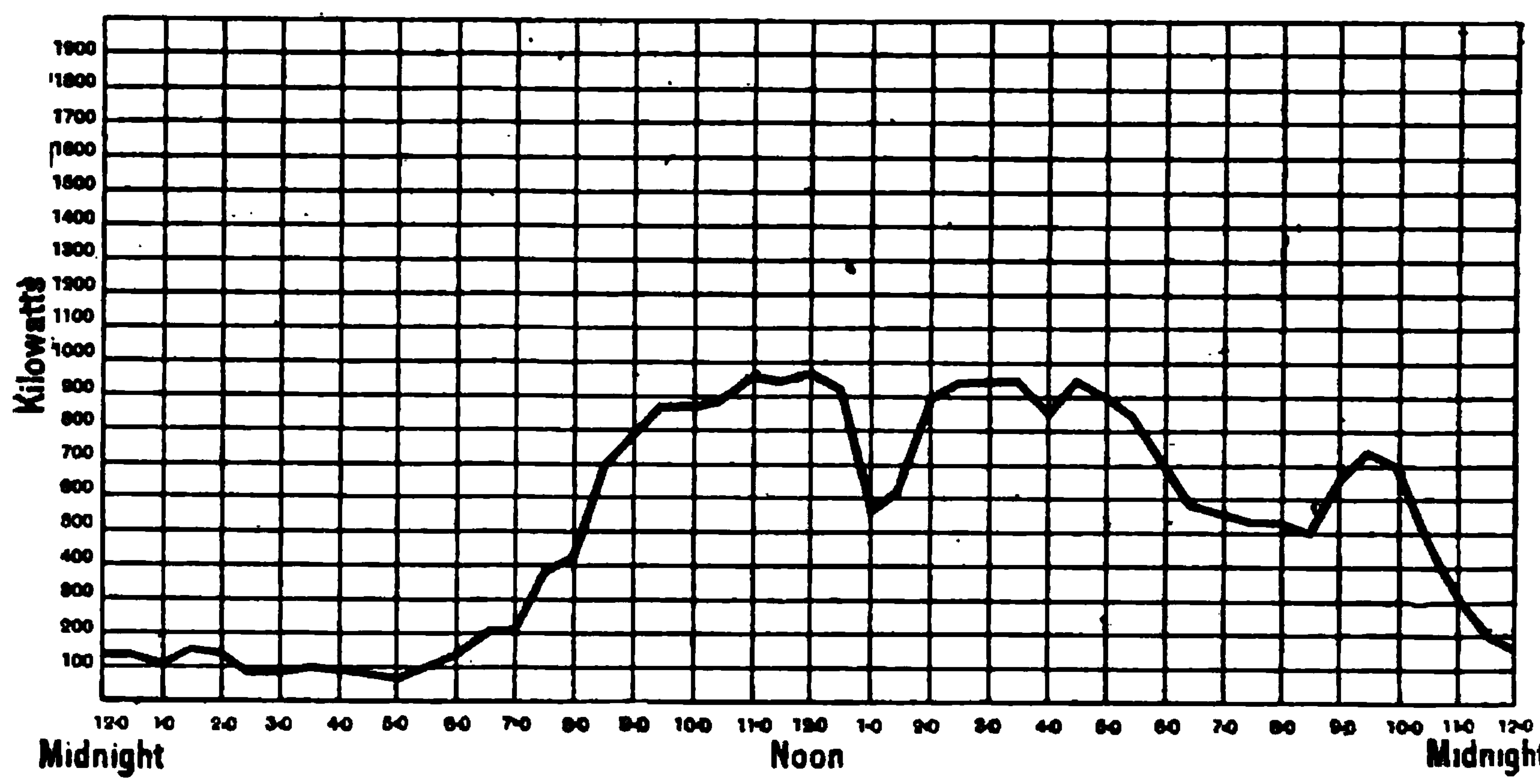


FIG. 125.—Load curve for a summer day.

practically certain to be overwhelmingly great, if a radius of 20 or 30 miles be contemplated.

Some actual load curves may now be given as concrete examples of what is met with in practice.

In figs. 125, 126, and 127 are given three thoroughly representative curves of the load on the Manchester station in 1899. These are typical of a large industrial town; the leading characteristics of the load are that it is almost wholly derived from shops, warehouses, offices, hotels, clubs, theatres, and factories, with a very small proportion of residences. The meagre residential load is due to the size of the town being such that nearly all the dwelling-houses are in the suburbs instead of in the town itself. In addition to the loads enumerated, there is a large demand for motive power, amounting to some 1500 H.P., part of which is required during the night for printing offices. There is in Manchester practically no street lighting.

With these prefatory remarks, we may examine the curves in detail.

That in fig. 125 represents a fine summer's day in July, that in fig. 126 a winter's day, and that in fig. 127 a very foggy day in winter.

The summer's day curve shows that there is a small load of 130 kilowatts at 12.30 a.m., this falls and then suddenly rises for about half an hour between 1.30 and 2 a.m., probably on account of some motors driving printing machinery being switched on. The load then falls away until 5 a.m. when it begins to rise, and increases rapidly until 8 a.m., the cause being chiefly the turning on of lamps by office cleaners. From 8 a.m. there is a very rapid increase until 9 a.m., by which time most business places are fully occupied and motors at work, and the demand becomes steady. At 10 a.m. there is another small rise, and the demand keeps steady until 12.30 p.m., when there is a most marked drop amounting to nearly 40 per cent. of the load; in about an hour's time the load is again rising rapidly, until at 2 p.m. it has attained nearly its old value. This important dip in the curve is due to the motors being stopped during the dinner hour. When readings of the load are taken every five minutes instead of half-hourly, as in the case from which this particular load curve was plotted, the fall and rise are seen to be very sudden. The load remains very steady except for a small, and more or less accidental, drop at 3.30 p.m. until 5 p.m., when it begins to fall off rapidly until 6 p.m., at which hour it reaches practically the same value as during the dinner hour. The bulk of the motors are now stopped, the demand coming chiefly from lighting in basements and similar places in which there is little natural light. At 8 p.m. the evening lighting load comes on and attains a maximum at 9.30 p.m. This is well below that for motive power, and is derived chiefly from hotels, restaurants, and theatres, there being very few private houses supplied. From 9.30 p.m. the demand falls steadily until midnight.

Speaking generally, the curve is seen to consist of a steady demand of about 520 kilowatts for lighting from about 8 a.m. to about 10.30 p.m. Superposed on this are two very decided humps, amounting to about 390 kilowatts, of steady demand, each covering about four hours, and separated by an interval of a little over an hour. Lastly, at 9.30 there is a very modest, and almost insignificant 'peak' of 175 kilowatts steadily attained and receded from, the total maximum at the peak being about 740 kilowatts.

Such, then, is the demand in the summer time on a plant capable of delivering 5250 kilowatts, the maximum demand at any time during the day not exceeding 960 kilowatts, though this demand is very steadily maintained. The load factor, reckoned on the maximum demand for the day, is 56 per cent., but on the whole plant in the station only 10¼ per cent.

How different is the case in the winter. Here, referring to fig. 126, the load at 12.30 a.m. starts from 287 kilowatts and falls quickly to 183 kilowatts, after which it slightly diminishes until 4.30 a.m., when it begins

to rise. At 5.30 a.m. the rise becomes rapid, until, at 6.30 a.m., the rate is so augmented that in an hour the load has increased over 90 per cent. This rapid increase is well maintained until a maximum of 2175 kilowatts is reached at 11.30 a.m. The same sudden drop is again experienced as was

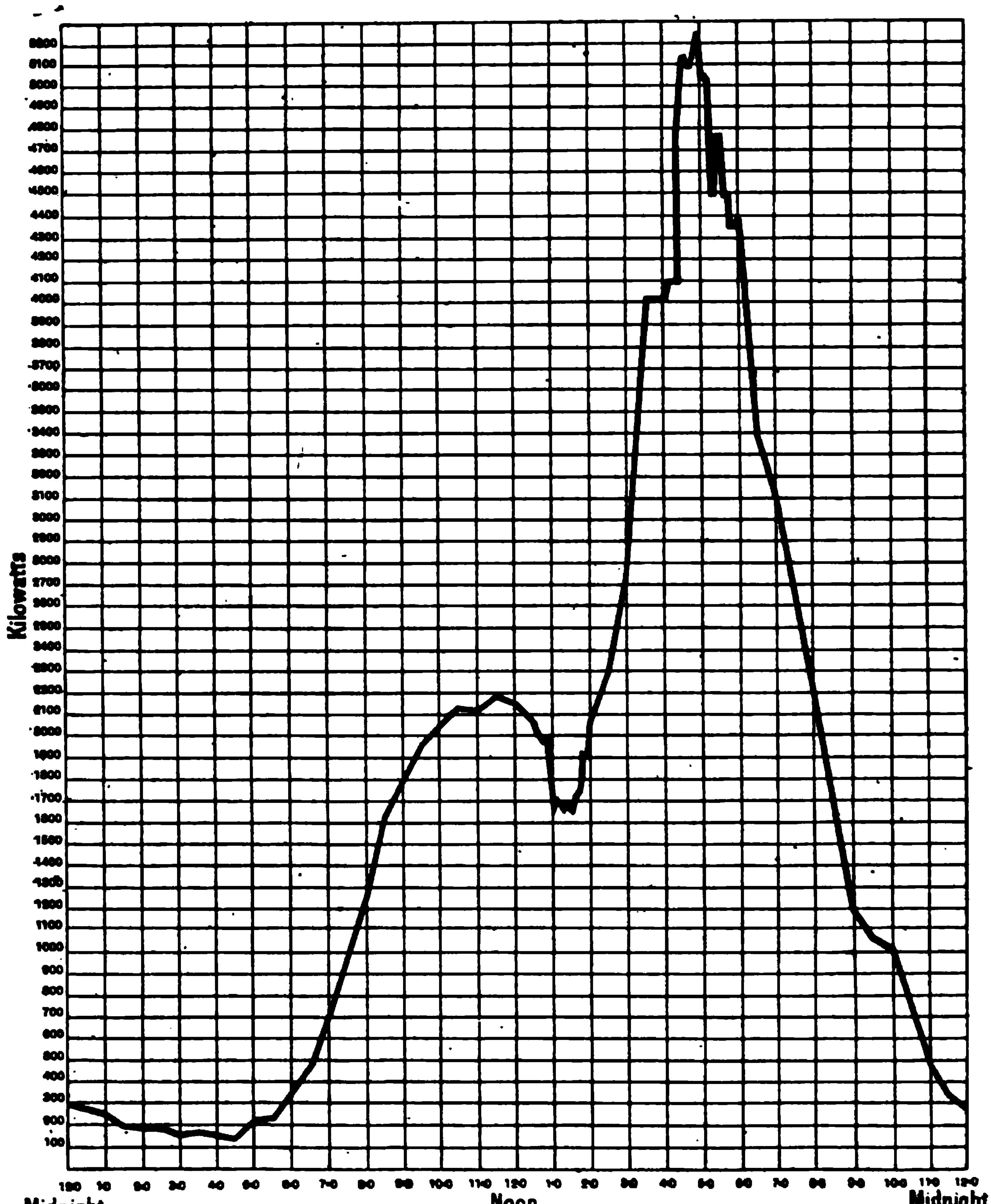


FIG. 126.—Load curve for a winter day.

noticed in the summer day's curve at the dinner hour, and is of practically the same amount. The dinner hour over, a rise sets in which is maintained until the maximum, 5250 kilowatts, is reached just before five o'clock, the rate being exceedingly rapid. From this point, the load falls nearly as

abruptly as it rose, until, at 6.30 p.m., it has fallen to about two-thirds of its maximum value. It continues to drop off rather more slowly until 9 p.m., after which it diminishes still more slowly till 10 p.m., when it falls quickly to only 270 kilowatts at midnight.

This curve displays a marked difference in character compared with the one for the summer season. The demand, instead of being fairly uniform, shows a greatly accentuated 'peak' of short duration and great magnitude. It occurs at 4.30 instead of at 8 p.m., and has grown from 740 kilowatts to 5250 kilowatts. It is interesting to note that the maximum value attained barely endures for five minutes, while after an hour the demand has very distinctly fallen off. The load factor calculated on the maximum demand for the day is not nearly so good, being only 32½ per cent. instead of 56 per cent., but with regard to the maximum capacity of the station it is immensely improved, having risen from 10½ per cent. to 32½ per cent.

The reasons for the altered nature of the curve are sufficiently obvious. The increase in load in the early morning is due to the same cause as in the summer, namely, the need of light for the cleaning out of offices, etc., but this demand increases far more rapidly than in the summer, because, in addition to the motive power, a large amount of light is required on account of the dull weather. The motive power load is practically unchanged, and the sudden drop in the dinner hour is as marked as in the summer; but to the motive power demand after dinner is added that for lighting, owing to daylight failing early. About five o'clock, every consumer, to whatever class he belongs, requires light, and the total demand becomes very great for a short time.

If a series of load curves for a year be examined, it will be observed that the peak gradually becomes higher, and at the same time shifts backwards in point of time as winter is approached. A certain critical time is reached between 5 and 6 p.m. when the bulk of the warehouses and offices close. If it be daylight at this hour the peak is moderate, but once the time of year is reached when this period of the day is dark, the peak suddenly leaps up.

In fig. 127 is shown the effect of a fog. Here from 9.30 to after 6 p.m. the demand never falls below 3500 kilowatts, and, for the greater part of the time, is greatly in excess of this figure. The same characteristic drop at the dinner hour is seen, but somewhat accentuated, no doubt because a number of lamps are turned off as not being required when the motors cease working. Here the load factor is 45 per cent. calculated on the maximum demand for that day, or 41 per cent. calculated on the maximum capacity of the station. The number of units generated on the foggy day is 32 per cent. in excess of that on the ordinary day; the maximum demand being actually 5½ per cent. less.

We may now examine a summer and a winter curve from a town of as totally different a character as it is possible to conceive, namely, Blackpool,

which is practically wholly a seaside holiday resort, and may be taken as typical of this class of town. That shown in fig. 128 relates to a Saturday in July, and that in fig. 129 to a Thursday in December, both in the year 1896.

Before describing the curves, it may be pointed out that there are a

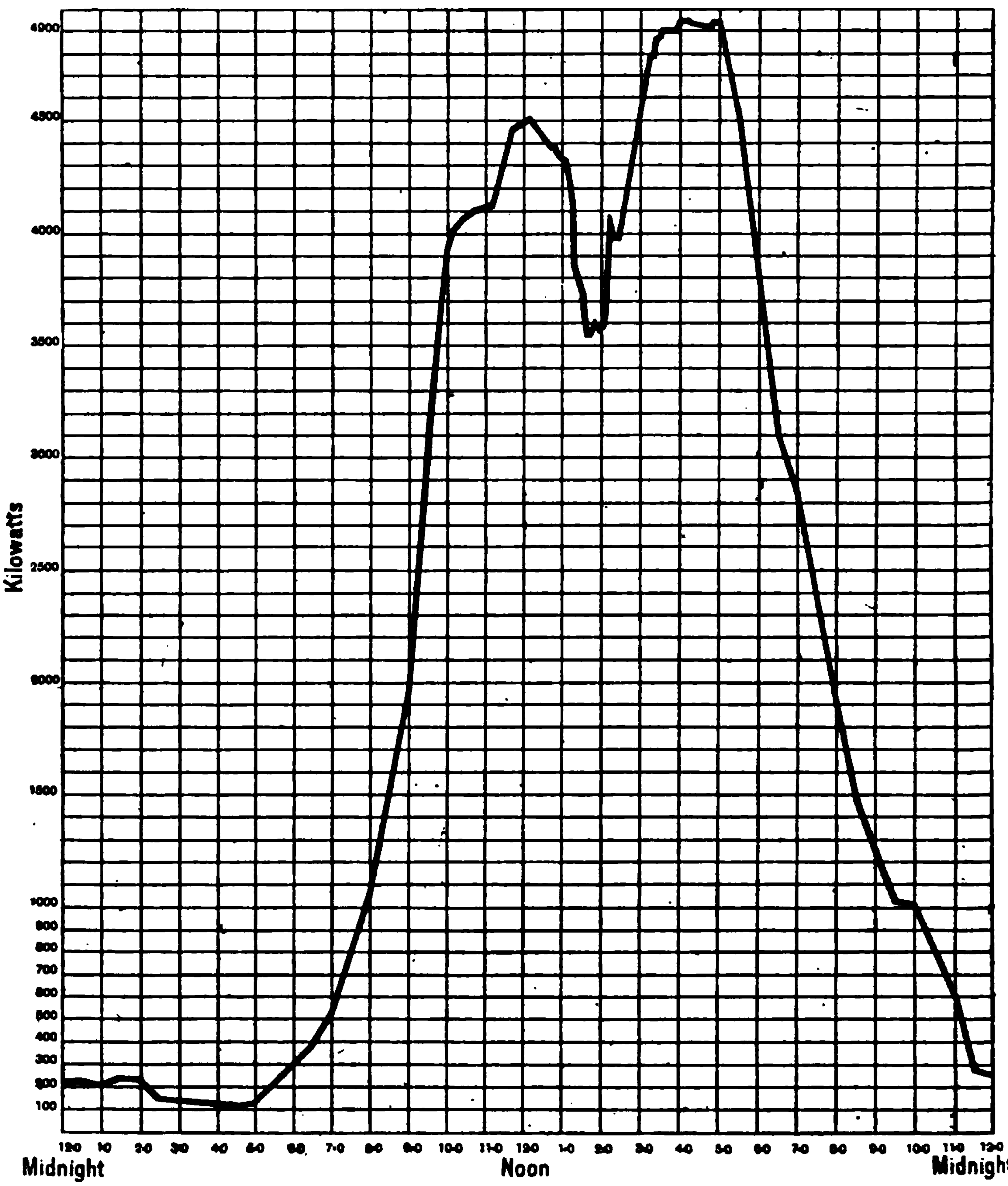


FIG. 127.—Load curve for a foggy day.

large number of places of entertainment in the town, and that it is a very favourite place for persons to spend a 'week-end' at; hence Saturday is the busiest day of the week. The demand for motive power, in any case limited, was practically *nil* owing to the current supplied being single-phase alternating. The rate of charge at the time referred to was a uniform one for all classes of consumer, and this again militated against any demand of a nature similar to motive power, *i.e.*, one extending over long hours, being supplied.

Taking first the curve in fig. 128, it will be seen that from midnight until 6 p.m. the demand is insignificant, except for a slight rise between 7 a.m. and 9 a.m., due, no doubt, to the same cause as in Manchester, namely, the

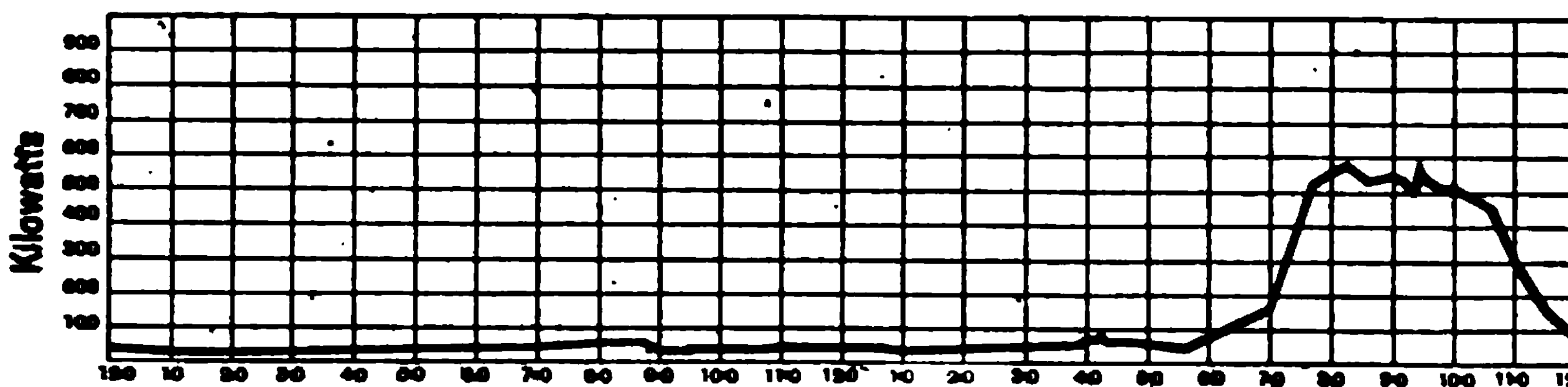


FIG. 128.—Load curve for a July Saturday.

cleaning of shops and offices. Between 4 p.m. and 5 p.m. there is a small sudden demand of short duration, probably due to some afternoon entertainment. At 6 p.m. the load begins to come on, and at 7 o'clock rises very rapidly to its maximum value, which is maintained very much longer than in Manchester, lasting about 2½ hours. At 10 p.m. a portion of the load begins to go off, and at 11 o'clock the fall becomes very rapid. The characteristic of this curve, then, is that there is practically no load from midnight onwards

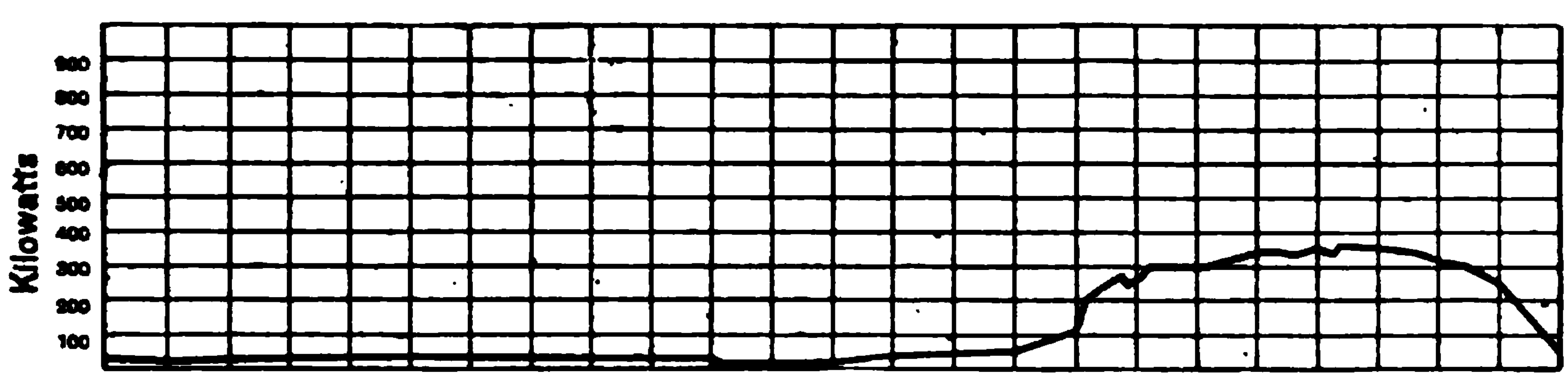


FIG. 129.—Load curve for a December Thursday.

and all day, but in the evening there is a steady load for some three hours. The daily load factor is 20 per cent.

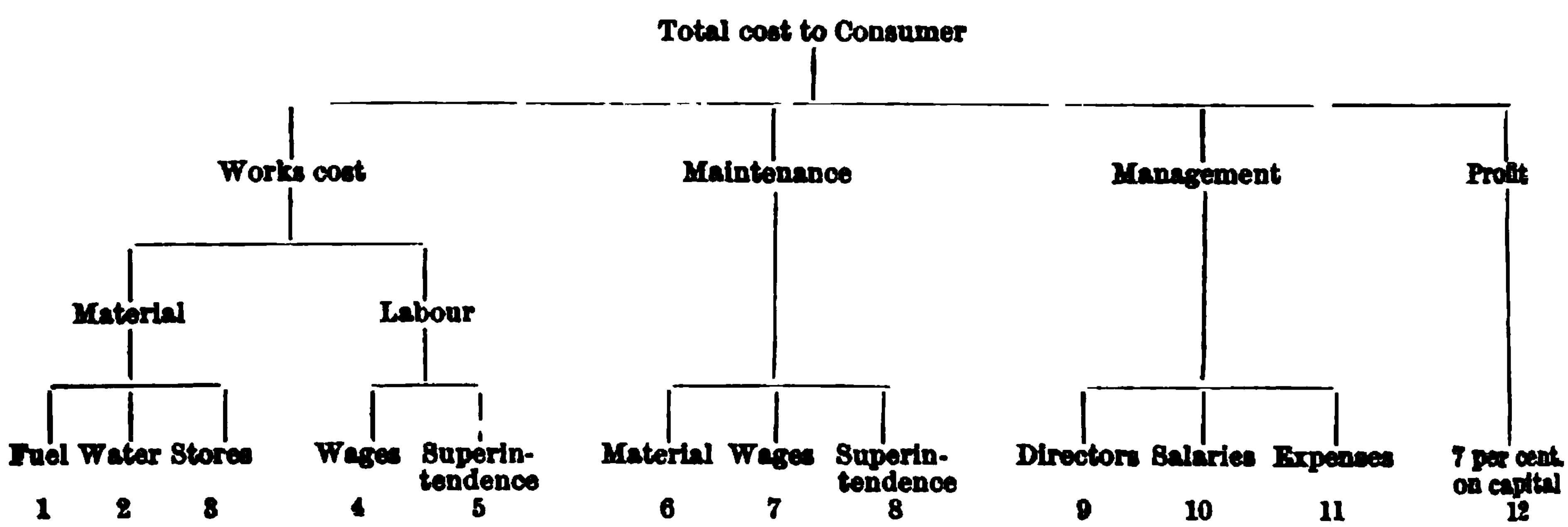
Turning to the winter curve, shown in fig. 129, the astonishing feature is at once noticed that the maximum load is very much less than that attained in summer, being, in fact, only about 62 per cent. of it. This is, of course, due to the practical desertion of the town in the winter, many places of entertainment and even shops being closed in the winter months. The hour at which the load comes on is, naturally, much earlier, namely, 4 p.m., and the load lasts correspondingly longer; with this exception, the load is similar to that in the summer, there being practically nothing after midnight and during the day, even the slight rise between 7 a.m. and 9 a.m. having disappeared. The daily load factor for the winter day is only 32, but is much better than the summer.

Considerable improvement in the nature of the load curves has been

effected by adopting a sliding scale method of charging, and in other ways since the time at which the curves illustrated were taken.

Mr Crompton was one of the earliest, probably the earliest, to study the question of cost of production, and as far back as 1886 he had begun to tabulate the costs at a large station in Vienna. The figures are set out in great detail in a paper published by him in 1888, but as these relate only to a 600 kilowatt plant, and they are now ancient history, it is not worth while reproducing them. Mr Crompton published two papers, one in 1891, the other in 1894, on the cost of generation and distribution, both of which have become classical. In the former, he introduced the term 'load factor' defined above, and showed its importance. In the latter, the subject is more fully treated, and it will be interesting to consider Mr Crompton's method of treatment and the figures he gives.

The entire cost of the energy delivered to the consumer he divides into four main heads, viz. :—Works cost, Maintenance, Management, and Profit. These are further subdivided as follows :—



Mr Crompton then goes on to consider the case of a station having an annual output of five million units, and apparently assumes a load factor of twenty per cent. as being quite the highest that can be hoped for for a long time to come. He then calculates what the cost of each item will be under the best conditions of working, giving in detail the process by which he arrives at each figure. These 'ideal' costs he tabulates as follows :—

1.	Fuel,	0·27
2.	Water,	0·01
3.	Petty stores,	0·02
4.	Wages,	0·10
5.	Superintendence,	0·10
6.	Material on repairs,	0·20
7.	Wages on repairs,	0·15
8.	Superintendence,	0·05
9. 10. 11.	Management,	0·42
12.	Profit,	1·68
		3·00

In the case of a municipal undertaking, item No. 9, directors' fees, is absent, and item No. 12, profit, will be subdivided into interest, sinking fund, and payment in relief of rates.

The whole of the figures are derived from results obtained in actual practice, and are exceedingly valuable. It will be noticed, however, that the classification of the costs is very different from that detailed above, and no separation between the standing and running charges is made, so that these figures are not of such general application as those given by Dr John Hopkinson; and it is not easy to compare them with his, though it is interesting to note that for a twenty per cent. load factor, Dr Hopkinson's figures work out to just under twopence per unit.

It will be interesting to now turn to the actual costs attained in practice. This matter has been very closely studied by Mr Hammond, and the figures published each year in the returns made for the Board of Trade have been analysed and compared by him in every conceivable way. The results are full of interest and are most instructive, but, unfortunately, there are so many unknown factors that there is great danger of erroneous conclusions being drawn. In all probability, more can be learnt as to the costs of production by the careful study of a single station where all the data are at hand; at the same time the published figures are very useful.

Mr Hammond in his analysis goes on quite different lines to Dr Hopkinson. He disregards the standing charges arising from capital expenditure, but takes the whole of the coal and wages as running charges. He has, in fact, very little choice in this respect, for no one but the engineer actually in charge of each station, and often not he, can accurately gauge the standing portion of these charges. Mr Hammond calls the sum of the following items the 'Works Costs':—(1) Fuel; (2) oil, waste, water and stores; (3) repairs and maintenance. To the works costs he adds the sum of (1) rent, rates, and taxes; (2) management, salaries, stationery and printing, general establishment charges, law expenses, insurance, etc., and the result he terms the 'Total Costs.' This expression is not a happy one, since it is liable to be most misleading, for, as already shown, the capital charges are the most important portion of the whole.

If the nature of the items included, however, be borne in mind, no error will arise. The costs are calculated, not per unit generated, but per unit sold, hence they are not strictly costs of production, but depend largely on the system of distribution and transmission adopted. They are thus deprived of some of their value, but there is no choice in the matter, for the units generated are rarely accurately measured.

In examining actual results attained, it must be remembered that the cost depends not only upon the general principles enunciated, but upon local conditions and the prices of various commodities and rates of wages. Thus, if energy be produced in exactly similar quantities, and at the same

rate, in two different places, so that the general conditions are identical, the actual costs of production may be very different. Much will also depend on individual management, for the opportunities of waste are very great; and a number of small savings may effect a substantial reduction in the cost.

It is impracticable to enter into the matter in great detail; a few of the lowest costs may, however, be quoted. They relate to nine provincial stations, and are as follows:—

	Bradford, 1896. Units Sold, 813,623.	Brighton, 1896. Units Sold, 1,388,821.	Edinburgh, 1896–7. Units Sold, 1,721,557.	Glasgow, 1896–7. Units Sold. 1,497,842.	Leeds, 1897. Units Sold, 833,280.	Liverpool, 1896. Units Sold, 844,617†.	Manchester, 1896–7. Units Sold, 2,508,588.	Portsmouth, 1896–7. Units Sold, 839,392.	Whitehaven, 1896. Units Sold, 178,378.
	d.	d.	d.	d.	d.	d.	d.	d.	d.
Fuel, ...	0·40	0·69	0·31	0·45	0·25	0·50	0·40	0·56	0·49
Oil, waste, water, and stores, . . .	0·11	0·10	0·06	0·07	0·05	0·07	0·11	0·15	0·12
Wages, ...	0·42	0·35	0·20	0·32	0·35	0·32	0·26	0·22	0·54
Repairs and maintenance, ...	0·10	0·30	0·06	0·48	0·13	0·25	0·17	0·39	0·29
Works Costs, .	1·03	1·44	0·63	1·32	0·78	1·14	0·94	1·32	1·44
Rent, rates, and taxes,	0·31	0·21	0·17	0·25	0·08	0·07	0·20	0·09	0·09
Management, . .	0·47	0·39	0·33	0·35	0·64	0·56	0·31	0·30	0·22
Total Costs, .	1·81	2·04	1·13	1·92	1·50	1·77	1·45	1·71	1·75

† Half-year only.

The two following tables, also taken from Mr Hammond's paper, show the lowest costs obtained in the United Kingdom for three successive years, by stations having outputs ranging from 100,000 to 3,000,000 units and over.

"Works Costs."

Units Sold (Kilowatt-Hours).	1894.			1895.			1896.		
Between	Place.	Year of Operation.	Cost per Unit Sold.	Place.	Year of Operation.	Cost per Unit Sold.	Place.	Year of Operation.	Cost per Unit Sold.
			d.			d.			d.
100,000 and 200,000, .	Huddersfield,	1st	1·85	Aberdeen, .	1st	1·20	Blackburn, .	1st	1·26
200,000 and 350,000, .	Leeds, . .	1st	2·17	Preston, . .	3rd	1·47	Preston, .	4th	1·00
350,000 and 600,000, .	Brighton, .	3rd	1·81	Leeds, . .	2nd	1·46	Newcastle District, .	6th	1·44
600,000 and 1,000,000, .	Kensington, .	4th	2·11	Edinburgh, .	1st	0·92	Leeds, . .	3rd	0·96
1,000,000 and 1,500,000,	Manchester, .	1st	1·49	Liverpool, .	12th	1·48	Glasgow, .	5th	1·32
1,500,000 and 2,000,000,	St James's, .	5th	1·93	Manchester, .	2nd	1·22	Edinburgh, .	2nd	0·63
2,000,000 and 2,500,000,	Westminster,	4th	1·74	..	..	..	St James's, .	7th	1·25
2,500,000 and 3,000,000,	Metropolitan,	6th	3·50	Westminster,	5th	1·51	Manchester,	3rd	0·94
3,000,000 and upwards,	..	..	..	City of London,	4th	2·46	Westminster,	6th	1·24

"TOTAL" COSTS (see Remarks above).

Units Sold (Kilowatt-Hours).	1894.			1895.			1896.		
Between	Place.	Year of Operation.	Cost per Unit Sold.	Place.	Year of Operation.	Cost per Unit Sold.	Place.	Year of Operation.	Cost per Unit Sold.
			d.			d.			d.
100,000 and 200,000, .	Norwich, .	1st	2·54	Burnley, .	2nd	2·22	Whitehaven, .	3rd	1·75
200,000 and 350,000, .	Leeds, . .	1st	3·11	Dundee, . .	3rd	2·30	Preston, . .	4th	1·94
350,000 and 600,000, .	Brighton, .	3rd	2·30	Leeds, . .	2nd	2·05	Norwich, .	3rd	2·11
600,000 and 1,000,000, .	Kensington, .	4th	2·86	Edinburgh, .	1st	1·67	Portsmouth, .	2nd	1·71
1,000,000 and 1,500,000,	Manchester, .	1st	2·17	Charing Cross,	4th	2·21	Glasgow, .	5th	1·92
1,500,000 and 2,000,000,	St James's .	5th	2·94	Manchester, .	2nd	1·80	Edinburgh, .	2nd	1·13
2,000,000 and 2,500,000,	Westminster,	4th	2·69	..	..	..	St James's, .	7th	2·29
2,500,000 and 3,000,000,	Metropolitan,	6th	4·52	Westminster,	5th	2·31	Manchester, .	3rd	1·45
3,000,000 and upwards,	..	..	..	City of London,	4th	3·50	Westminster,	6th	2·09

The average Works Costs for all the stations in the kingdom, as given by Mr Garcke, are shown in the following table. They are not classified in the same manner as those worked out by Mr Hammond, and the only items omitted are Depreciation and Sinking Fund.

Year.	Number of Undertakings.	Generation.	Distribution.	Rents, Rates and Taxes.	Management.	Special.	Total.
		d.	d.	d.	d.	d.	d.
1895,	60	2·45	0·36	0·35	0·81	0·10	4·07
1896,	61	2·13	0·26	0·28	0·62	0·08	3·37
1897,	84	1·97	0·26	0·24	0·57	0·06	3·10
1898,	98	1·79	0·25	0·22	0·49	0·06	2·81

Mr Hammond naturally endeavours to draw conclusions from the mass of figures collected and arranged by him, but the task is a difficult one, owing to the number of factors that are either unknown or cannot be allowed for, and for this reason they must be received with some reserve. Mr Hammond, strangely enough, regards load factor as secondary in importance to output. This is contrary to all theoretical considerations, as we have seen, though output may be expected to have a considerable effect. Probably, the reason for Mr Hammond's course is that he leaves out of consideration, as already stated, the greater part of the standing charges, the very part of the cost most affected by the load factor.

It is interesting to note some representative load factors of widely different stations. These particular load factors are the ratio of the units actually generated (not sold in this case) to the product of the average of the maximum demands at the beginning and end of the year, and the number of hours in the year. The reason for so calculating the load factor is to make

allowance for the increase in the number of consuming devices during the year.

Name of Place.	Load-Factor on Basis of Average Maximum Demand.
Bradford,	10·82
Brighton,	17·00
Bristol,	14·74
Edinburgh,	16·56
Glasgow,	12·36
Leeds,	16·34
Manchester,	14·30
Portsmouth,	17·76
St James's,	16·39
Westminster,	15·94

The actual expenditure of the various stations in respect to capital may now be compared. Here again, a mere tabulation of figures is but little guide to the expenditure that may be anticipated as necessary in any particular case, because local conditions vary so much. Thus, in a given undertaking, the cost of mains may appear unduly high, though this may be by no means the case, for the district may be a very straggling one, or else a large area may have been covered at once with mains before many consumers have applied for current, while the generating plant has only been put down of sufficient size to deal with the actual demand at the time. The effect of such a proceeding would obviously be to make the cost of mains per kilowatt of plant appear very high, though the policy might nevertheless be a sound one, for, by covering a large area, the number of possible consumers in the early stages of the undertaking is largely increased, and work found for the generating plant; after a few years, the disproportion would disappear. Again, in another case, the expenditure on generating plant might seem abnormal. This would be due to the opposite course being pursued, and the initial instalment of plant being a large one. The object of this would be partly to be able to employ large generators, partly to get ahead of the demand. However laudable the latter may be, and, however desirable it may be to have large units of plant, it does not seem so sound a policy as the other. The following table gives the average percentage expenditure on the various items of capital expenditure as compiled by Mr Garcke :—

Year.	Number of Undertakings.	Land and Buildings.	Plant and Machinery.	Mains.	Meters.	Instruments.	Provisional Orders.
1895,	52	22·3	36·7	32·2	3·2	1·4	3·1
1896,	64	21·1	35·9	35·1	3·3	1·2	3·3
1897,	81	20·0	37·0	34·2	4·4	1·3	2·5
1898,	92	19·0	36·2	35·7	4·5	1·3	2·1

It is interesting to note how nearly the same is the expenditure on plant and on mains, while the cost of land and buildings is seen to be a very heavy factor. This last item is likely to have its relative importance greatly diminished as the scale of operations increases, and the use of larger units of plant becomes permissible. Again, the cost of mains should also diminish as the undertaking grows, for the distributing network having to be laid down of practically full size at the start, it will take some years before it is fully loaded.

It is an important matter to carefully record the whole of the items of cost in working a central station. The Board of Trade has laid down a definite form in accordance with which all accounts must be kept, and, in consequence of this, the costs are distributed under the headings which have been referred to when quoting from Mr Hammond's statistics, though, as we have seen, they do not enable one to properly distinguish between the standing and running charges.

The forms in question are eight in number and relate to (1) Loans, (2) Capital Account, (3) Revenue Account, (4) Net Revenue Account, (5) Sinking Fund Account, (6) Reserve Fund Account, (7) General Balance Sheet, (8) Statement of Electricity generated and sold.

The forms for both municipal and company undertakings are practically identical, except with regard to a few items which need not be entered into here.

In order to carry out the Board of Trade's intention with accuracy, it is necessary that great care be taken to properly classify every item of expenditure.

Every account should be stamped with the name of the heading to which it is assigned, and it must, of course, also be marked as to whether it is Capital or Revenue.

It is sometimes doubtful as to the exact class to which a given account should be assigned; and it may therefore be of use to give some of the principal accounts the Author has found it necessary to open, together with illustrations of the kind of expenditure regarded as coming under each.

First as to the Capital Account. The principal items are as follows:—

(1) *Land.*—This includes the purchase price and all the legal and other expenses incidental to acquiring the land, and the expenses necessarily incurred, in many cases, for paving the streets abutting on it.

(2) *Buildings.*—This account will comprise the engine and boiler houses, foundations for generators and all plant, coal bunkers and all parts forming a portion of the structure and permanent fittings, such as the wiring for lighting the works, etc. The same account also includes the offices and their permanent fittings, together with the cost of paving yards, providing drainage, etc. The various items enumerated will constitute sub-headings

of the main account, and a subdivision devoted to sundries will be found necessary.

(3) *Machinery.*—This account should be subdivided so that a separate account may be kept of the principal items, such as boilers, stokers, economisers, pumps, cranes, generators, switchboards, etc.

(4) *Sub-stations.*—A separate account should be kept for each sub-station and be subdivided for the various items, such as transformers, switchboards, secondary batteries, boosters, sundries.

(5) *Mains.*—This account will include many different items of expenditure, among which may be mentioned :—(1) Conductors, subdivided into (*a*) cable and (*b*) strip. (2) Pipes and Culverts, including insulators, pipes, cement, bricks, sand, gravel, broken stone, culvert flags. (3) Draining. (4) Solid system, comprising troughing, bitumen, bridges, jointing materials. (5) Flagging and Paving. (6) Cartage and Sundries. (7) Consumer's main fuses.

(6) *Meters*, including meter boards and insulators.

(7) *Instruments.*

We now turn to the Revenue Accounts, which are as follows :—

(1) *Generation.*—This comprises the following headings :—(1) Coal. (2) Oil, consisting of dynamo, cylinder, and castor. (3) Waste and rags. (4) Water. (5) Engine room stores. These include a great variety of articles, among which may be mentioned engine packing, jointmaking materials and similar asbestos and rubber goods, gauge glasses, brushes for generators, white metal, bolts, nuts, unions and couplings, steam piping, steam fittings, valves for general use, polishing paste, emery cloth and similar materials, ropes and belts for subsidiary plant; if these last are used on the main generators, however, a separate account of them should be kept.

(2) *Repairs.*—This account includes the upkeep of the whole of the buildings and plant on which the capital has been expended. It has three main divisions, each of which is subdivided into a number of heads. They are (*a*) Generating Station, including Buildings, Lighting of Station, Boilers, Stokers, Economisers, Pumps, Cranes, Generators, Switchboards, Instruments, Transformers or Motor generators, etc.; (*b*) Sub-stations. For each sub-station a separate account is kept, comprising the following :—Buildings, Lighting, Transformers or Motor generators, Secondary Batteries, Switchboards, Sundries. (*c*) Distribution. The account relating to this includes the upkeep of Mains, Meters, Accessories such as Main Fuses, Sundries. To the above must be added Street Lighting if this be undertaken; this account will include repair of apparatus, new lamps and sundries, carbons for trimming, painting of lamp posts.

(3) Next to the maintenance of plant, and closely connected with it, is the provision of *tools*. All these are charged to Revenue Account and the stock at the end of the financial year is valued. The difference between the

amount of this valuation and the sum of the valuation of the previous year *plus* the amount expended during the year represents the cost of the wear and tear of tools during that period. The wear and tear is apportioned among the Works Orders in proportion to the cost of labour booked to the respective orders.

(4) *Management expenses.*—These comprise miscellaneous office expenses, and those connected with meetings of directors or committees, travelling expenses of officials, stationery, printing, stamps, advertising and insurance. To the same account are charged the salaries of engineers, permanent officials, and the clerical staff.

(5) *Rents, rates and taxes.*—These comprise ground rents, ordinary rates and taxes, water rates for purposes other than generation, electricity and gas, telephones.

(6) *Interest* on loans and Sinking Fund payments.

(7) *Sundry* expenditure, comprising, among other items, law and Parliamentary charges, stamp duty, commission on loans, official clothing for men provided with uniforms (if any), interest on deposits exacted from consumers as security for payment of their accounts, and compensation paid in respect of claims for personal injury consequent on operations carried on in the streets (such claims are usually fraudulent, but in most cases it is best to settle them without going into court), office furniture.

The foregoing brief review of the various items of expenditure is by no means complete, and will not apply equally to all undertakings, but it will serve to give a general idea of the way in which the expense should be apportioned. It will, of course, be understood that with the exception mentioned in Revenue Account No. 4, nothing in the nature of wages is included, these being quite distinct.

The wages, nevertheless, require quite as careful analysis as the accounts, and it will be found convenient to have a Wages Book, ruled with columns headed to correspond with the Board of Trade standard form of annual return of expenditure, with such additional headings as may be necessary for items that require further subdivision. The books devised by the Author are shown in Forms 7 and 8. They are two in number, partly in order to keep them of reasonable size, and, partly, because it is convenient to keep the wages of the men engaged on outside work distinct from those of the indoor staff. In both books, the letters and numbers show the precise heading to which the items belong in the Board of Trade form.

The particular books shown make provision for a weekly deduction for a thrift or pension fund, and a provident or sick fund, which may or may not be arranged by the Undertakers for their employés.

Examples of the kind of work assigned to the various heads are shown below.

F. 1. *Clerical Staff.*—The wages coming under this heading are suffi-

FORM 7.—Wages Book (Indoor)—Showing the open folio, two pages facing each other.

252 ..... Electric Light and Power Co.

No.	NAME.	OCCUPATION.	Time.	Rate.	Total for Week.	Deducted on Account of Thrift Fund.	Deducted on Account of Provident Society.	Amount Paid.	F. 1 Clerical Staff.	A. 1 Coals.

FORM 8.—Wages Book (Outdoor).—Showing the open folio. Size 16½" by 25½".

250 .... Electric Light and Power Co.—Street Mains Department.

No.	NAME.	OCCUPATION.	Time.	Rate.	Total for week.	Deducted on Account of Thrift Fund.	Amount Paid.	Cap. 3 Buildings.	Cap. 6 Conductors.	Cap. 8 Meters.

ze 16½″ by 25½″.

Wages Account for Week ending..................................190............ 252

ANALYSIS.

REVENUE.								CAPITAL.			
	Repairs, Maintenance, and Renewals.										
A. 3 [G]eneration.	A. 4 Buildings.	A. 4 Machinery, etc.	A. 4 Tools.	B. 1 Distribution.	Apparatus Distributing Station.					Street Lighting.	Cap. 3 Buildings.

Wages Account for Week ending..................................190............ 250

ANALYSIS.

CAPITAL.					REVENUE.					
							Repairs, Maintenance, and Renewals.			
Street Lighting.	Tramways.						A. 4 Buildings.	B. 2 Mains.	A. 4 Tools.	B. 1 Distribution.

ciently obvious, comprising those of the whole of the clerks proper, timekeepers, storekeepers, meter readers, office boys, messengers, etc.

A. 1. *Coals.*—The wages charged to this heading are those of the men engaged on unloading the coal and operating the coal handling plant. The stokers and others do not come under this heading, but under the next.

A. 3. *Generation.*—This comprises the wages of all men actually engaged on the various parts of the process of generation, viz.:—Switchmen, dynamo attendants, drivers, greasers, cleaners, stokers, coal trimmers, pumpmen, yardmen, etc.

A. 4.—Under this heading are three subdivisions, viz.:—Buildings, Machinery, and Tools.

A. 4. *Buildings.*—This includes the wages of men engaged on the upkeep of the fabric of the building and fixtures, other than plant, connected therewith; among these are joiners, painters, plumbers, wiremen, and men of other trades.

A. 4. *Machinery.*—The men employed on repairing and maintaining the plant, have their wages accounted for under this heading; they are fitters, labourer, smiths, pattern makers, drivers when engaged on fitter's work, etc.

A. 4. *Tools.*—Smiths are the men usually engaged on repairing these, with, occasionally, fitters.

B. 1. *Distribution.*—The staff of the Installation Department comes under this heading, viz.:—Inspectors, fuse cleaners, etc.

Apparatus in Distributing Stations.—The wages of men engaged in maintaining the plant in repair.

The whole of the above items are chargeable to revenue. The only two capital items in this book are Street Lighting and Buildings.

Street Lighting.—This heading provides for the wages of men engaged in erecting new lamps.

Cap. 3. *Buildings.*—This provides for the wages of draughtsmen engaged on extension work, and Clerks of the Works watching the construction of buildings.

We now pass on to the second Wages Book.

In this a heading is included for Buildings, Cap. 3, to allow for the wages of men engaged on small extensions to them, such as bricklayers, concretors, etc.

Cap. 6. *Conductors.*—This includes the wages of all men engaged on extensions of mains, viz.:—Foremen, gangers, jointers, cable layers, concretors, bricklayers, masons, flaggers, labourers, watchmen, etc.

Cap. 8. *Meters.*—The meter fixers engaged in fixing meters for new consumers or for additional circuits, are comprised in this.

Street Lighting Cap.—This heading is provided for such men of the Mains Department as may be engaged in erecting new lamps.

Tramways.—This is a heading only required in those undertakings having traction work attached to them.

The remaining items are revenue charges and comprise:—

A. 4. *Buildings.*—This heading is repeated in this book to allow for the wages of men of the Mains Department engaged in the upkeep of buildings.

B. 2. *Mains Rev.*—This comprises the wages of the men enumerated under "Cap. 6. Conductors" when engaged in repairing or maintaining mains already laid. The district foremen's wages in a growing undertaking are charged partly to Capital and partly to Revenue. In one that had arrived at a steady state, the whole would be charged to Mains Revenue.

A. 4. *Tools.*—This item is repeated to allow for smiths attached to the Mains Department for sharpening picks, wedges, etc.

B. 1. *Distribution.*—Sundry wages are charged to this, the most important being those of meter fixers engaged in exchanging meters, of junction box cleaners, and of men looking after disconnecting and similar apparatus on the mains.

In practically analysing the wages, the heading to which a given Works Order (see Chapter XL.) is to be assigned is carefully determined, and this then gives the classification of all the time booked to this Works Order, thus greatly simplifying the work of the clerk making up the Wages Book.

It is held by some that weekly returns of the costs should be made, and some engineers profess to do this. It is difficult to understand, however, how it is possible to arrive at weekly costs when accounts are paid monthly; and the cost of such items as oil, waste, engine-room stores cannot be arrived at with any approach to accuracy unless taken over a fairly long period.

The question of depreciation is a most important one. It is sometimes maintained that since electrical plant must be maintained in a state of complete repair, if it is to operate at all, and since such repairs are charged to revenue, no depreciation account is necessary. This, however, is not sound, for no matter how well maintained a plant may be, it will, in process of time, become worn out, and have to be replaced. It is, therefore, prudent to have a fund to meet this depreciation, and a certain amount should be written off the profits each year. Examples of the amount allowed in two typical instances are given below:—

	Glasgow. Per cent.	Aberdeen. Per cent.
Land and buildings,	1	1
Machinery and plant,	7½	5
Accumulators,	10	...
Mains, services, and cables,	2½	1½
Meters,	7½	5
Electrical instruments,	5	2½

These figures may be compared with figures given by Mr Crompton in his 1894 paper, which are actual costs obtained over four consecutive years. They are as follows:—

Buildings,	0·65 per cent.
Boilers,	5·23 ,,
Engines,	1·77 ,,
Dynamos,	0·76 ,,
Other plant,	1·90 ,,
Accumulators,	3·25 ,,
Mains and services,	0·36 ,,
Meters,	2·50 ,,

Closely connected with depreciation, but distinct from it, is amortisation, or the becoming obsolete, of plant. In a rapidly growing industry, such as electrical generation, improvements are constantly being effected, so that plant often has to be abandoned long before it is worn out. Again, rapid expansion of work may render it imperative to substitute large machinery for small, although the latter may be in perfect working order. To meet such cases, a Renewals or Reserve Fund should be built up. If this be done, the year in which the actual renewal takes place is relieved by the prosperous years which have gone before, and its works costs are not then unduly heavy, so that the dividends, or the rates, as the case may be, do not suffer. The average percentage on the whole Capital set aside for both depreciation and reserve by a number of undertakings is shown in the following Table:—

Name of Place.	Percentage to Average Capital Outlay during the Year.
Glasgow,	6·36
Aberdeen,	2·60
Bradford,	3·46
Norwich,	4·18
Leeds,	4·08
House-to-House,	3·96
St James's,	3·89
Sheffield,	3·59
Kensington,	3·38
Westminster,	2·96

In the case of Municipal undertakings, the Local Government Board requires that the Capital shall be redeemed in a certain number of years, usually not exceeding twenty-five, and for this, a Sinking Fund has to be created. The annual payments to be made are not a fixed percentage, but are calculated from Tables into the construction of which it is not necessary to enter. The instalments to be paid increase annually. Thus, a particular loan of £50,200 was raised, and had to be repaid in twenty-five years. The first instalment was £1376, 17s. 7d., while the last would be £2798, 18s. 1d. Inasmuch, however, as the annual sum to be paid for interest diminishes as

the capital is reduced by the operation of the Sinking Fund, the increasing amount of the instalment is not felt.

Companies are under no obligation to provide a Sinking Fund, and very rarely do so.

In the case of companies, the distribution of profits does not call for much consideration, for, after the payments to the various funds just mentioned, there only remains the payment of a dividend. In the case, however, of Municipalities, the matter is different. They are compelled by their Provisional Orders to reduce the price charged to their consumers if they make more than five per cent. net profit, but it is a moot point whether it is justifiable to make any profit at all.

From one point of view, it is wrong to make a profit out of the section of the ratepayers who use electrical energy, and to apply the money to relieving the rates of the whole community. On the other hand, it is urged that the money is borrowed on the security of the rates, and that any loss sustained has to be made good by the whole body, although the benefits accruing from the provision of electric supply are only enjoyed by a section. Hence the community is entitled to some payment for the risk.

There is a certain amount of reason in both contentions, and probably the best solution is to make a small payment in relief of the rates each year, but certainly not nearly such a large sum as has been paid by some Municipalities. From the point of view of the undertaking, there can be no doubt that a profit should not be made, for the lower the price, the greater the demand, and the lower the cost of production.

If no profits be handed over to relieve the rates, it is fairly obvious that a Municipality can produce energy more cheaply than a company, for it only has to pay from 2½ to 3½ per cent. for its capital, while shareholders have a right to expect a much higher rate as a return on their investment; also the work done by directors has to be paid for by a company, while the same duties are performed gratuitously by a committee. It is sometimes stated that municipal work is extravagantly conducted, and that there are abuses which do not exist in companies, but statistics go to show that municipal electrical undertakings are worked as economically as those of any companies, and more so than those of most.

CHAPTER XXX.

METHODS OF CHARGING.

THE price charged for a commodity is an all-important factor in determining the demand for it, and this is especially true of electrical energy. So long as the price remained high, it could only be regarded as a luxury, and, as such, its field was necessarily limited. Every reduction in price caused a great widening of the sphere of influence, and, for cheap electrical energy, the possibilities are almost limitless, for its applications are to every branch of industrial enterprise, and every day sees fresh developments.

We have already seen how the cost of production is governed, and the principles enunciated will point to the direction in which reduction in price is to be looked for.

The earliest method of charging was by contract, a certain sum per annum being charged per lamp fixed. This crude device was resorted to, practically on account of *force majeure*, there being at the time very few, if any, commercially practicable meters, though, even now, this system is still in use, in some cases, in America.

The iniquity of charging the same sum per annum for a lamp fixed in, say, a club, and in an office closing at four or five o'clock, must be patent to all, but a few examples may be given to show how the actual consumption varied from that assumed by the charge. They are taken from consumers who had previously been supplied at a contract rate which, at the then price of energy per unit, corresponded to an assumed user of three hours per day throughout the year.

In order to have a common basis on which to compare consumers, irrespective of the number of their lamps, the percentage that the quantity used bears to the maximum quantity that could be used if each lamp burnt for 24 hours per day is taken; for each of the consumers compared, a curve is plotted having this percentage as ordinates, and weeks as abscissæ. A whole year is given in each case, but unfortunately it is not possible to give the same year for each. The contract rate corresponds to a percentage of 12½, so that the curve formed by setting this up as ordinate, each week is a straight line, and the area of the rectangle represents the total quantity of

energy assumed to be taken during the year. In order to find whether the contract rate corresponds with the consumption, it is only necessary to compare the area enclosed by the curve representing the actual consumption with that of the rectangle; if this be greater than unity, the contract rate is too low, if less, it is too high.

Fig. 130 represents the consumption at a theatre; the ratio of the areas is 1·4, showing that the consumer is only paying for about two-thirds of his consumption.

Fig. 131 shows the case of a restaurant; here the ratio is 1·3.

Two widely different shops are shown in figs. 132 and 133 respectively. The former is a West End jeweller's, and the ratio is 1·02, showing that the contract rate is almost exactly correct. The latter shows a West End china merchant's, in which the ratio is only 0·3, the consumer actually paying more than three times as much as he would by meter.

Lastly, fig. 134 shows a library, in which case the ratio is 0·5, or the consumer pays twice as much as he would if charged on his actual consumption.

The first step in advance was made when meters were introduced. These showed the number of ergs or coulombs dissipated in the consumer's installation, and a charge based on this was, at any rate, somewhat less empirical than the earlier system, though still far from proportional to the cost of producing the energy supplied.

Both systems, though wrong in themselves, had in them the germ of the correct principle, which must be sought in their combination.

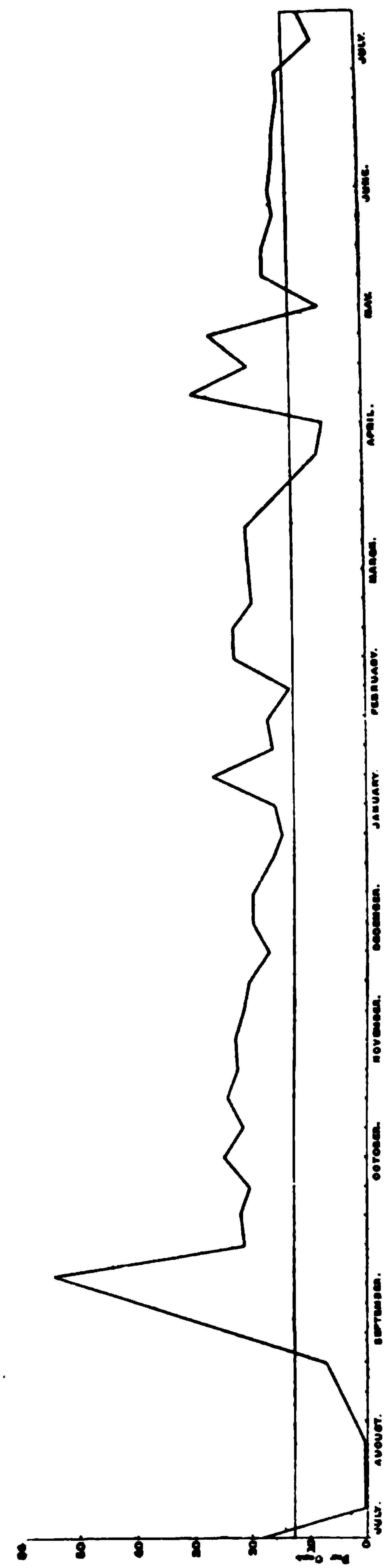


FIG. 130.—Consumption in a theatre.

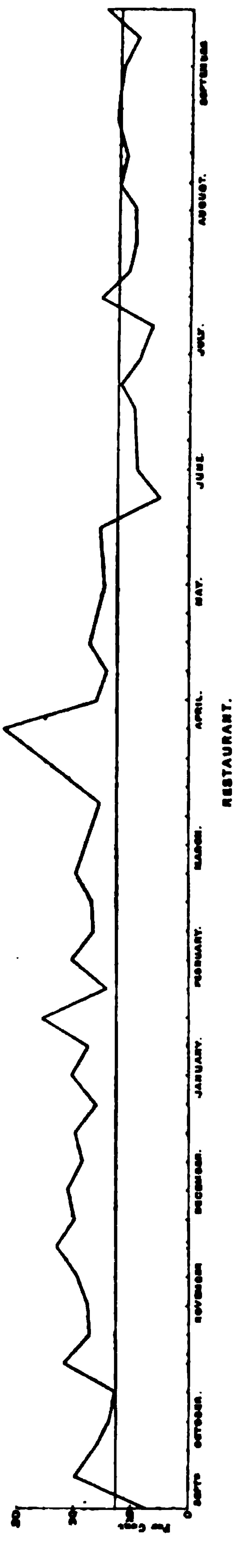


FIG. 131.—Consumption in a restaurant.

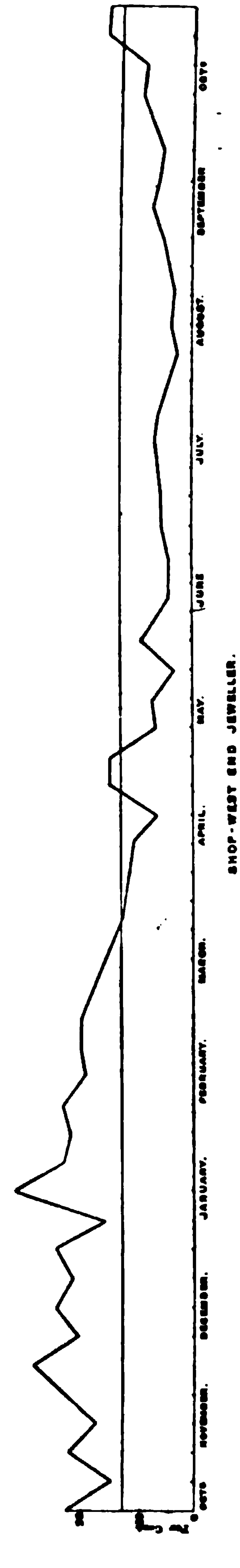


FIG. 132.—Consumption in a shop—West-end jeweller.

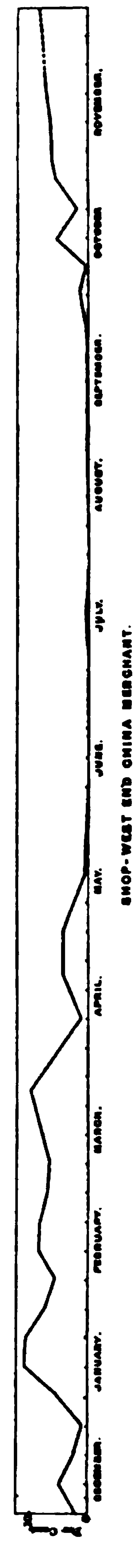


FIG. 133.—Consumption in a shop—West-end china merchant.

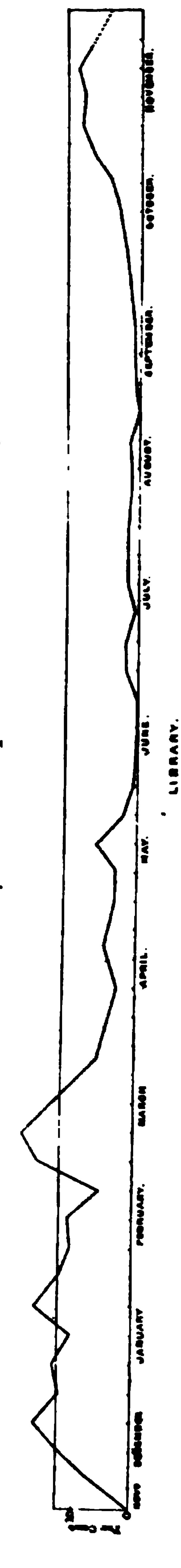


FIG. 134.—Consumption in a library.

We have seen that the cost of production comprises two parts, one proportional to the demand in kilowatts, the other to the consumption in kilowatt-hours. The contract system took account of the former, and ignored the latter, the meter system regarded only the latter.

Dr Hopkinson was the first to recognise the correct principle,* and, as far back as 1883, he had introduced into Provisional Orders, with which he had to do, a special method of charge, intended to secure some approach to proportionality of charge to cost of supply. As often happens, this foresight was lost to view, and it was not until 1893 that the principle was put to practical work, being for the first time acted upon at Manchester and Whitehaven, almost simultaneously.

The system consists in a compound charge comprising an annual charge per kilowatt, as in the old contract method, *plus* a charge per unit as in the system which had succeeded it.

The Hopkinson method aims at obtaining a uniform rate of profit from all classes of consumer, the fixed charge per kilowatt being intended to represent the standing charges, and the charge per unit the running charges.

The effect of such a system is to provide a perfectly continuous sliding scale whereby the average price per unit automatically falls as the length of user increases. The price, in fact, may be said to be asymptotic to the price per unit, continually approaching it, but never reaching it, for, no matter how many hours the demand may extend over, the fixed charge is always there, though, being spread over a continually increasing number of units, its amount per unit is ever diminishing.

A numerical example will show clearly how this method works out. Suppose the fixed charge to be £7 per kilowatt per annum, and the charge per unit to be 1½d., the Table on the next page shows the average price per unit for different numbers of hours of consumption per annum.

An examination of this table will reveal several interesting points. Bearing in mind the principle upon which the system is based, and assuming that the values assigned to the two factors of the charge are suitably chosen, it will be seen that whatever the average price for a particular number of hours may be, the price is merely proportional to the cost of production, and hence it is at once obvious how costly to supply are those consumers who only use the energy for short hours. Again, for moderately long-hour consumers, the fixed charge is of far greater importance than the charge per unit, being 2·8d. against 1½d. for a 600 hours user; on the other hand, for very long-hour consumers, the charge per unit is the all-important one, the fixed charge having become insignificant.

In practice, of course, no such charge as 1s. 6d. per unit is ever made,

* The Author believes that Mr Crompton and Mr Bromley Holmes very early introduced sliding scales of payment and afterwards abandoned them, but he has no particulars of these.

the price being limited by the Provisional Order under which the undertaking is carried on, usually to 8d. per unit. The table is therefore not applied above this higher limit, the consumers using the supply for shorter hours than those corresponding to this, being charged the limiting price. The inferior limit to the price, it will be seen, is set by the number of hours in the year, this being the highest figure by which the fixed charge can be divided. The artificial limit set by the Provisional Order does not alter facts, and any consumer, therefore, who uses the supply for a shorter time than that corresponding to the limit yields a smaller profit than the others, and, if the time be very short, every such consumer represents a loss to the undertaking.

It is worth pointing out how immensely superior this method is to any

Number of Hours.	Amount of Fixed Charge per Unit Consumed.	Running Charge per Unit Consumed.	Average Price per Unit Consumed.
	d.	d.	d.
100	16·80	1·25	18·05
200	8·40	1·25	9·65
300	5·60	1·25	6·85
400	4·20	1·25	5·45
500	3·36	1·25	4·61
600	2·80	1·25	4·05
700	2·40	1·25	3·65
800	2·10	1·25	3·35
900	1·86	1·25	3·11
1000	1·68	1·25	2·93
1200	1·40	1·25	2·65
1400	1·20	1·25	2·45
1600	1·00	1·25	2·25
1800	0·90	1·25	2·15
2000	0·80	1·25	2·05
3000	0·56	1·25	1·81
4000	0·42	1·25	1·67
6000	0·28	1·25	1·53
8000	0·21	1·25	1·46
8760	0·19	1·25	1·44

system of discounts based upon any given consumption or hours of user. Such discounts have frequently been tried, but with unsatisfactory result; they usually take the form of a certain price per unit being charged up to a certain consumption, say, 10,000 units per annum, while above this and below 20,000 units, the price is something less, while for a consumption exceeding 20,000 units it is something less still. All such discounts have the inherent defect that it is possible by an increasing consumption to lower the total amount charged as well as the average price. It is obviously wrong to charge less for 10,001 units than for 10,000, though it is right that the average price per unit should be less.

An illustration may be taken from an actual tariff introduced by a London Company some years ago. The ordinary charge for energy was

6d. per unit, but the following discounts were given according to the quantity of energy consumed during the year, irrespective of the consumer's maximum demand.

No. of Units consumed per Annum.	Discount.	No. of Units consumed per Annum.	Discount.
Over 3,000	1 per cent.	Over 15,800	9 per cent.
,, 4,000	2 ,,	,, 18,500	10 ,,
,, 5,100	3 ,,	,, 21,700	11 ,,
,, 6,300	4 ,,	,, 25,400	12 ,,
,, 7,700	5 ,,	,, 30,000	13 ,,
,, 9,300	6 ,,	,, 36,200	14 ,,
,, 11,200	7 ,,	,, 45,000	15 ,,
,, 13,400	8 ,,	,, 60,000	16 ,,

To show the weakness of this tariff, consider the case of a consumer taking 44,999 units in the year. His account would amount to £967, 9s. 7d. If now he is wise, and burns two more units, his account will actually be diminished to £956, 5s. 5d., or if he prefer to still spend the same amount of money on his lighting, he can have 527 units for nothing, which hardly appears profitable to the company. Again, the small consumer with few lamps, who yet burns them for long hours, gets no reduction in price, although the energy he consumes may have cost the company less than half the amount per unit, that the energy consumed by their large consumer did, while the heavy reduction made to the latter may result in no profit being made on the supply to him.

In using the Hopkinson system of charge, it must be remembered that its nature is such that it levels up all consumers, the "good" long-hour consumer only yielding the same rate of profit as the "bad" short-hour one, though, of course, the turnover is greater in the former case.

The maximum demand may either be determined by measuring the current flowing when all lamps or other consuming devices are connected to the circuit at the standard pressure, or else by inserting a recording instrument which will show the maximum demand actually reached in practice. The figures obtained from the same installation in the two ways may differ greatly, and are almost certain not to be the same, for very few consumers turn on all their lamps simultaneously; indeed, the average maximum demand on the whole station rarely exceeds 65 per cent. of the total lamps fixed. It appears, therefore, at first sight, unfair to charge on the number of lamps fixed instead of on those actually alight simultaneously, but, seeing that the annual standing charges to be met at the station are the same, however the price be based, the only effect is that the charges are met by a lower price per kilowatt based upon a larger number of lamps. This assumes, of course, that all consumers are treated alike, and that the actual

maximum demand of each is the same proportion of the number of lamps fixed in his installation. This latter assumption is incorrect, and to this extent the method is unjust.

It is often objected that this system discourages the fixing of lamps which are only used occasionally, and it is urged that this should not be done, because they may be used when others are extinguished, so that they swell the consumption without increasing the maximum demand. This is the only important drawback, but is readily got over, to a great extent, by connecting all such lamps to a separate meter, the consumption through which is charged at the limiting price allowed by the Provisional Order.

If the fixed charge be based upon the measured maximum, it should be upon the maximum found during the year, and not upon the maximum in each quarter, for it is the highest maximum that determines the standing charges.

It is sometimes objected that, inasmuch as the maximum demands of all classes of consumer do not take place simultaneously, the method is faulty. Undoubtedly, strictly speaking, this is so, but practically the injustice is small, and to attempt to allow for it would be an unnecessary refinement.

The measurement of the maximum demand calls for an instrument that shall be simple, cheap, reliable, sluggish and without inertia. Such an instrument, invented by Mr Arthur Wright, has already been described in Chapter XXV. In conjunction with a modification of the Hopkinson system, devised by himself, it has done much towards popularising that system.

When used with the Hopkinson system, the scale is simply graduated in amperes, but when used with the Wright modification, a different arrangement is adopted.

Instead of charging each consumer a fixed sum per annum for each kilowatt of maximum demand, irrespective of his consumption, and then a sum per unit actually consumed, Mr Wright prefers to require each consumer to use a fixed number of units per annum, for which he is charged a price so calculated that it will cover both the fixed charge for the installation and the running charge for the minimum number of units consumed, and all units in excess are charged only for the running charge.

Thus, if, in each case, the running charges be £7 per annum per kilowatt *plus* 1½d. per unit, the charge would, in the original Hopkinson system, be made in this form, but in the Wright system, it would be said that for the first hour a day (*i.e.* for the first 365 units) the charge would be 6d. (actually in the case taken 6·1d.), and after that for all units in excess, 1½d. If the initial number be not reached, such units as are taken are thus charged at the maximum price.

The scale of the instrument when used in conjunction with this system, is graduated in such manner as to show the number of units that must be consumed in the half year before the lower price is charged. Thus a con-

sumer whose maximum demand indicator read, say, 300, would be able to tell by looking at his ordinary meter whether he had reached this number; if he had, all extra units would be charged at the lower rate, if he had not, he would know that the higher rate was still in operation.

In practically working this system, Mr Wright, does not take the maximum as his basis, but the mean of six winter months readings, on the ground that the maximum demand is not made by all consumers simultaneously, and he allows an exceptional maximum demand to be made, on previous notice being given, without taking note of it in the mean; it is somewhat difficult to see any logical reason for this, however, though it may be good policy.

Again, he does not divide his two charges in proportion to the actual division of the costs, but makes the running charge relatively heavier, with the object of compensating the undertaking for the loss made on supplying those consumers who do not reach the number of units necessary to pay the fixed charge. This course, which is resorted to also when using the Hopkinson system, appears to be perfectly sound, though rather hard on the long-hour consumers.

It is quite clear that, in many cases, the maximum demand of a consumer will fall in the summer months far below that in the winter months, and hence, it is absolutely necessary that readings should be taken in the latter before an account is rendered. Thus, a consumer first taking the supply in April cannot have his account rendered until the following December, and every consumer must have his account spread over two quarters, one a summer, the other a winter, quarter. Although by a somewhat complicated arrangement of adjustments this requirement may be slightly modified, the fact remains that it is a very serious drawback to the system, and in some cases is sufficient to prevent its adoption.

Another system of charging is based upon the assumption that it costs less to produce energy between certain hours of the day than at some other period. This necessitates the use either of two meters switched in and out of circuit at stated times, or else a single meter that will register at an increased or diminished rate during a certain period of the day. The latter is the one usually preferred in the few cases in which the system is used.

A switch, operated by a clock, is employed to shunt the main coil of the meter between certain hours, during which the maximum demand is assumed not to occur on the station. The effect is to cause the meter to register a certain fraction of the energy actually consumed during the hours that the meter is shunted, and hence, for these hours, a lower price per unit actually consumed is charged, although a uniform price is charged for the quantity indicated by the meter.

The use of a shunt applied to a conductor of such low resistance as the main coil, especially when the connections have to be frequently made and

broken by a switch, is attended with great risk of error, and an improvement consists in making the switch alter the arrangement of the windings of the meter, if it be an ampere-hour one, or insert resistance in the shunt circuit, if a watt-hour meter.

In the former case, one half of the main coil is operative during the period of lessened price, and the entire coil during the assumed period of maximum demand. In the latter case, a resistance is inserted in the shunt circuit during the period of lessened price.

A remarkable example of the same principle introduced into only one town, and recently abandoned there after being in use for a good many years, consisted in using in the consumers' premises discontinuous integrating meters, having relays operated by means of a current sent out from the generating station at stated intervals of time, the impulses being controlled by a clock. A distinct circuit from the station is thus required for every group in a street or district. The varying rate of charge is effected by halving the number of impulses between certain hours of the day. The objections to such a system are numerous, the most obvious being the complication and liability to interruption of the record, a large number of meters being affected if a single circuit go wrong; the excessive inconvenience of providing special circuits direct from the generating station for the meter relays, and the power placed in the hands of the Undertakers to alter accidentally or otherwise the registration of the whole of the meters on the circuit, and that without any permanent or discoverable alteration in the meters.

This principle of altering the rate of charge according to the hour of the day has been strongly advocated, and is frequently in evidence in the catch phrase 'day-load.' It is quite unsound, and is by no means a practical one; the abrupt change in rate at a given instant cannot be justified, and the time of actual maximum demand is continually shifting according to the season of the year, so that, to be consistent, the clock-actuated switch should be operated at a different hour each week or month, though, even were this done, the time limits would remain quite arbitrary. The system is attended with a good deal of complication and liability to error.

A great fallacy seems to underlie much that is written concerning methods of charging. The consumer appears to be regarded as a person who devotes his time to watching his electric meter, and who has to be 'encouraged' to turn on his lamps by means of various kinds of inducements in the shape of lower rates for longer hours of consumption. In other words, it seems to be assumed that a man will deliberately turn on his lamps because he can get his energy at a lower rate per unit, though his total account is increased. Surely this is bargain-hunting run wild!

The real purpose served by a sliding scale based upon the length of user is, not that it induces consumers already taking the supply to use it longer, but that it renders it possible for a different class of consumer, normally

using his lamps for longer hours than those already connected, to avail himself of the supply which he would be unable to do unless the price were brought down. Thus, a consumer using his lamps an hour a day can well pay 5d. per unit, whereas one requiring light all day long would find the cost at that rate absolutely prohibitive, though he can afford to pay 2d. per unit, and will, moreover, save money by discarding gas for electric light at this price.

It cannot be too strongly impressed on suppliers of energy that a consumer will take his supply as, and when, it suits him to do so, and that his own convenience is the only thing that he will consider. They may as well accept the fact that nothing that they can do will make him burn his light, or use his motor, a single minute more than he needs to do so; what they must seek to do is to attract those consumers whose avocations or habits necessitate their using the supply for long hours for their own convenience, and in order to do this, they must have a sliding scale which will cause the price to diminish to such consumers to such an extent as to enable them to save money by giving up the illuminant which they have been in the habit of using.

It is by no means uncommon for the rate of charge to be made to depend on the class of demand, a different rate being charged for energy supplied for motive power and heating from that for lighting.

Such a course is logically unsound, for the cost of production of a given quantity of energy at a given rate is absolutely unaffected by the purpose to which that energy is applied.

On the other hand, from a commercial standpoint, it can readily be justified. A demand for energy for motive power or heating usually implies a very large consumption, and it is perfectly defensible to accept a lower rate of profit on a larger turnover.

The proceeding amounts, in fact, to a special bid for a particular class of consumer. Unless a low price be charged for motive power or heating, electrical power cannot compete with other agents, and hence the alternatives are a very large consumption at a price giving a lower rate of profit than in the case of an ordinary lighting consumer, but a large aggregate profit, or no consumption at all; obviously the former course is the one to be preferred.

The difference in the two prices charged often appears to be disproportionately great, but in reality it is less than it, at first sight, appears. A motive power load is almost invariably a long-hour load, and hence the cost of production is low. It will be convenient to take a concrete case to consider. In Manchester, the maximum price for lighting is 5d. per unit, the original Hopkinson sliding scale being in operation if 448 hours of user per annum are exceeded, the charges being those shown on p. 359, viz., £7 per annum per kilowatt of maximum demand, *plus* 1¼d. per unit. For motive power there are two rates; if the consumer can show that the

exigencies of his business require that he shall use his motors for 48 hours per week (*i.e.* just under the ordinary factory hours), the fixed charge of £7 per annum, enforced in the case of lighting, is remitted, the price being then only 1¼d. per unit. If the length of user be less than this, he can choose between the ordinary lighting sliding scale or 2½d. per unit.

Now, for 48 hours per week, or, say, 2500 hours per annum, the ordinary lighting rate works out to an average of 1·92d. per unit (see Table on p. 360), so that the amount actually remitted is only about ⅔d. per unit.

Again, in the case of motors supplied at 2½d. per unit, this price corresponds to the average price by the ordinary lighting rate for a consumption extending over 1344 hours in the year, or only about 4¼d. per day. There are few cases where motors are employed in which they are used for shorter hours than this.

Another basis for reduction in price which is justifiable almost solely on commercial grounds, is the aggregate annual consumption. Discounts are sometimes given to consumers on the ground that they consume very large quantities of energy. Apart from the consideration that the large turnover is to be desired, and the fact that a single large consumer costs slightly less than a number of small consumers whose aggregate consumption is the same for certain items, such as service connections, meters, inspection, collection of accounts, etc., there is no appreciable lessening in the cost of production, and therefore correspondingly little reason for diminution of price.

The principle is, in fact, a dangerous one, and should only be admitted under the strictest safeguards. If a reduction based on the total quantity consumed be given at all, it should be but a small one, and should take the form of a discount on the account for all units consumed above a certain minimum number, and not on the whole account, otherwise the defect already pointed out, of the account actually diminishing for an increased amount of energy supplied, will not be avoided.

Thus, supposing it were determined to adopt this system, the ordinary price might be charged for all quantities up to 10,000 units; for all energy consumed above 10,000 and up to 20,000, a discount of 1 per cent. on the excess; for all above 20,000 units up to 30,000, a further discount of 2 per cent. on the excess above 20,000 and so on. These figures are purely for the purpose of illustration, and are not put forward to indicate what is actually to be recommended as the limits of consumption or rate of discount that is suitable.

A very special class of consumer is met with in certain towns to which reference should be made, namely, that of those consumers who have their own generating plant which they use under ordinary circumstances, but who have a service from the Undertakers, so that they may use the public supply in case of emergency.

Obviously, the only method of charge properly applicable to them is the

Hopkinson system of a fixed charge per kilowatt of maximum demand, *plus* a charge per unit consumed, for the expense to the Undertakers is almost wholly a standing charge, the actual quantity of energy supplied being usually very small. Unfortunately, this method cannot be enforced, as the maximum price to be charged to any consumer is limited by the Provisional Order, and the Company or Municipality finds itself entitled to charge only a few shillings for what has cost them perhaps many pounds in the shape of interest and establishment charges.

Such a state of things is obviously monstrously unfair, yet there seems no doubt that, as the law stands, the Undertakers can be called upon to give a supply, and cannot legally refuse to do so, though, as far as the Author is aware, the point has never been contested in a Court of Law.

In certain cases, as, for instance, in a town of moderate size having a large place of entertainment using the supply in this manner, the hardship may be so great as to involve a serious loss, and to meet such cases, the law should, unquestionably, be altered, so that either the Undertakers shall not be compelled to supply, or if the obligation be retained, they shall be entitled to charge such a sum as shall recoup them for their whole outlay in connection with the installation.

While insisting on the necessity for a Supply-Authority having the right to refuse to give the supply at the ordinary price to consumers having their own generating plant, it must not be lost sight of that in certain cases, especially in large towns in such streets as heavy mains are laid in, it is by no means a great hardship to give this "standby" supply, as it is called, but, on the contrary, as a matter of policy, it may be expedient to do so.

There are several considerations entering into the question which are not obvious at the first blush. In the first place, the consumer usually only runs his own plant during the hours of heaviest demand, and is only too glad to shut it down, and avail himself of the public supply when a comparatively small number of lamps are required. In this way a very considerable amount of energy may be sold at the maximum price, though taken just at those very times when the load on the station is least. The risk of the whole installation being turned over at the top of the peak, of course, remains.

The most important inducement, however, to give the supply lies in the fact that its superiority over that derived from the private plant, both as regards constancy of pressure and reliability, is almost certain to lead the consumer in time to abandon his machinery, and to take his supply permanently from the Undertakers.

As a matter of interest, particulars of a number of actual cases of standby connections are given in the following Table.

The kind of consumer, his maximum demand in kilowatts, and the number of units sold during each of four consecutive quarters, together with

the actual amount of the accounts of the respective consumers, are all shown. The total demand in kilowatts, arising from 15 consumers, amounts to just over 205 kilowatts, while the total revenue brought in by them all was £681 odd. This gives a revenue per kilowatt installed of £3⅓ per annum.

If the consumers be regarded as bearing their full share of the whole of the standing charges of the undertaking, this revenue would about cover the interest and sinking fund on the capital expenditure, leaving nothing for the remainder of the standing charges which consist of such items as wages and coal for being ready to run, etc., and nothing for running charges.

For the reasons stated above, however, it is exceedingly doubtful whether these standby connections really increase the standing charges to anything like the extent of the sum of their individual maximum demands,

Description of Consumer.	Maximum demand in Kilowatts.	Units, Quarter ending Dec.	Units, Quarter ending March.	Units, Quarter ending June.	Units, Quarter ending Sept.	Total Amount of Accounts during the Four Quarters. £	s.	d.
Offices, ...	24·7	627	232	120	128	29	19	5
Shipping Warehouse, .	15·5	...	298	681	3201	106	11	4
Warehouse, . .	10·3	1349	934	681	289	83	14	6
Warehouse, . .	28·7	...	722	232	352	33	15	1
Shop, ...	4·9	572	559	61	58	32	1	0
Stationer's Shop, .	45·8	34	38	3	16	5	1	0
Warehouse, . .	10·6	577	336	98	196	34	6	7
Bank, ...	6·8	328	536	113	92	28	6	6
Shop, ...	19·2	153	540	221	277	32	11	6
Shop, ...	9·5	538	307	200	238	34	0	6
Packing Warehouse, .	2·6	887	983	477	449	70	14	0
Warehouse, . .	7·3	446	606	148	126	34	15	0
Offices, . . .	1·9	...	...	2	15		18	2
Warehouse, . .	5·0	597	439	108	140	32	18	0
Bank, . . .	12·5	1412	2321	463	535	121	13	6

for it is most improbable that all, or even a large proportion of, the consumers would call upon the supply simultaneously, and therefore the actual increase of standing charges due to them was probably very small, and so the transactions were on the whole directly profitable, while a number subsequently dispensed with their own plant, and so were gained as permanent consumers.

Before concluding this chapter, a quarterly charge that is sometimes made to consumers, though not for energy, may be referred to, namely, the system of so-called 'free' wiring. This system has for its avowed object the affording of facilities to consumers for the installation of the electric light without their having to incur the heavy initial cost of wiring.

The *modus operandi* is for the Undertakers, or more usually a distinct company, to wire the premises without initial charge, having first, of course, made the necessary arrangements with the landlord. The tenant is then

charged a certain sum per unit consumed, over and above the ordinary price for energy, to recoup the parties who had wired his building for their expenditure. If the Undertakers carried out the work themselves, the whole revenue from the consumer is of course retained by them; if a separate company did the work the difference between the sum actually received and that which would have been received if the ordinary price had been charged, is handed over to the company by the Undertakers.

When the charge is made in the form just described, no more inequitable or impolitic system could well be conceived. By basing the charge on the number of units consumed, the price paid by the consumer for his wiring is made to increase with the number of hours he uses his lamps, so that the desirable consumer is actually penalised instead of encouraged, one burning his lamps five hours a day paying five times as much as one taking the light for only one hour per day, although the cost of wiring the premises of both consumers is identical. Again, the payment goes on in perpetuity, the debt never being extinguished.

Such a method of procedure could not be expected to commend itself to any person giving the matter a second thought, but it is easy to so modify it as to render it both equitable and highly advantageous to all parties. The quarterly charge should be made per lamp fixed, the Hopkinson system lending itself most readily of all to this, and the charge should be so calculated that the debt with interest is extinguished in a certain number of years, say five or seven.

With this modification, the hire purchase system may be strongly commended, and it is likely to be a valuable aid to the extension of the supply to middle-class houses and shops.

In calculating the rates, it must be borne in mind that a somewhat high rate of interest may rightly be demanded, for the risks are fairly great; the house may change hands, and the incoming tenant may not take the light, though experience shows that this is very improbable, or the house may remain unlet; again there is risk of damage by fire and of deterioration of the wiring by neglect or ill-treatment.

In some cases, the wiring has really been provided free, the Undertakers making no charge, and in other cases sharing the cost equally with the consumer. It is very questionable whether such a proceeding is not illegal, in so far as it amounts to giving individual consumers undue preference.

CHAPTER XXXI.

THE REGULATION OF CONSUMERS' INSTALLATIONS.

It is often contended that the responsibility of a Supply Authority ends at the terminals of their service mains, and that it is no concern of theirs if the user of their supply chooses to employ it for the purpose of igniting his premises; that bad wiring is not more dangerous than bad gas piping, and that any interference by the Undertakers on a consumer's premises is unwarrantable, tyrannical, and meddlesome.

Such views are seldom expressed by those actually engaged in the practical work of central station supply. They know only too well that unless they make and enforce certain regulations as to the amount of leakage, the balancing of lamps, the starting of motors, and similar matters, the steadiness of their pressure and the reliability of their service will be injuriously affected, and that to assert that they are unconcerned with what takes place beyond the terminals of their service mains, betrays a woeful or wilful ignorance of first principles. Every single consumer's installation forms an integral part of the whole system of distribution, and is, electrically speaking, one with it. If consumers were allowed to do as they liked, or rather as their contractors wished, public supply would become an impossibility, and this is equally true whether a company or a municipality be the Undertakers.

Apart from the necessity for regulations of the class indicated, it is very desirable to further in every way possible the efficient and safe wiring of installations.

On general grounds, contractors who desire to do their work well and conscientiously should be encouraged to the suppression of the 'jerry' wirer, whose prices are cut below the possibility of sound work being done.

For reasons more immediately affecting central station interests, every effort should be made to promote a feeling of confidence and satisfaction as regards electric light and power. If the size of the wire has been cut down to save expense so that there is an unreasonable loss of pressure in the installation, or if a bad quality of insulation has been put on the wire,

causing faults which make the fuses go and interrupt the supply, the consumer will be the last to blame his own parsimony or to suspect that his contractor was dishonest; he will simply blame the Supply Authority and accuse them of giving a low pressure or will be confirmed in his idea that the electric supply cannot be depended on.

Lastly, the Undertakers are under a moral obligation to protect the consumer, as far as possible, from the consequences of his necessary ignorance of electrical matters, and especially is this the case when they are a municipality.

One most serious danger from bad work lies in the possibility of its giving rise to fire, and it is incumbent upon every one to diminish this risk as far as possible in a crowded city, while in the interests of the Undertakers themselves, it is to be pointed out that a serious fire caused electrically would have a most damaging effect, not only upon their own business, but upon the prestige of electric lighting generally.

Much doubt appears to exist as to whether Undertakers have legal power to make and enforce regulations of the kind referred to. There can be no doubt that under Provisional Orders they have power to make such regulations as to the work on a consumer's premises as will prevent the consumer becoming a source of danger, or of an unsatisfactory supply being given to any other consumer. The clauses in the Order which are relied upon for this are under the heading of Supply, the words being:—

"Provided also that if the owner or occupier of any such premises as aforesaid uses any form of lamp or burner, or uses the energy supplied to him by the Undertakers, or deals with it in any manner so as to unduly or improperly interfere with the efficient supply of energy to any other body or person by the Undertakers, the Undertakers may, if they think fit, discontinue to supply energy to such premises as long as such user continues."

"Provided also that the Undertakers shall not be compelled to give a supply of energy to any premises unless they are reasonably satisfied that the electric lines, fittings and apparatus therein are in good order and condition, and not calculated to affect injuriously the use of energy by the Undertakers or by other persons."

In addition to these, there is given power, under the general Electric Lighting Act, 1882, Section 6, to any local authority to make bye-laws for securing the safety of the public in addition to those made by the Board of Trade for the same purpose, the proviso being made that such bye-laws shall have no force until confirmed by the Board of Trade.

Obviously this section of the Act confers no power on companies to make bye-laws, and it has become practically a dead letter so far as regards local authorities, the Board of Trade never having yet consented to confirm any such regulations.

It will thus be apparent that the power given under the Electric

Lighting Acts and Orders is extremely unsatisfactory, and does not by any means give the Undertakers a sufficiently strong hand to deal effectually with wiring contractors who dispute the regulations. In consequence of this, two, at least, of the large municipalities have obtained special powers for dealing with the matter; Glasgow, by a clause in the Glasgow Buildings Regulations Act 1892, and Manchester, by one in the Manchester Corporation Act 1897. It might be somewhat difficult for companies to obtain similar powers, but in their own interests, as well as in those of their consumers, it would be well worth while to seek to obtain the powers.

In certain cases, companies, and even municipalities, have undertaken the wiring of consumers' premises in addition to their ordinary duties as Undertakers, the chief object being to secure good work being done. Though the object may be effected, the drawbacks to this course are very great. By entering into competition with wiring contractors, the Undertakers create a feeling of soreness and opposition on the part of those who are otherwise their best canvassers, and in the event of their endeavouring to enforce their regulations, they are certain to lay themselves open to charges of unfairness, and unduly favouring the work of their own wiring staff. Again, the consumer is apt to regard the guarantee furnished by the Undertakers carrying out the wiring as applying to far more than the work for which they are actually and properly responsible. Lastly, the risk of financial loss attaching to wiring work is considerable.

The only justification, in the author's opinion, for Undertakers carrying out the wiring of consumers' premises would be in the case of a small town or village in which the amount of work would be insufficient to attract a competent contractor. Such a case might arise if a company supplied a number of villages from a single high-pressure station.

It may be worth pointing out here that, in a case such as that just mentioned, and even in towns of moderate size, it is highly desirable that the engineer to the Undertakers should be in a position to act as consulting engineer to the consumers. This would obviate the necessity for obtaining powers to enforce regulations, as he could draw up specifications for the wiring and, under the powers conferred on him personally by the contract, could enforce the carrying out of the work in a proper manner.

Apart from the facilities afforded in this direction, there would be other advantages both to the Undertakers and the consumers. Possible consumers are often lost because they are not in a position to know of themselves the advantages and disadvantages of electric lighting or power, and do not care to trust to an ordinary contractor for advice, while they would regard the engineer to the Company or Corporation as being in an independent position.

Owing to the similarity between the majority of the installations, the extra work entailed on the engineer would not be excessive, because it could be systematised and much of it be a matter of routine; for this reason, it

would be possible to render the services to the consumer for a low fee, and to those with small installations this would be an immense boon.

Against the plan here advocated, it would be urged by some that it introduces competition with consulting engineers. Why they should be exempt from this it is difficult to see; surely the engineer who permanently advises a single company has as much right to add to his income by a consulting practice, as a consulting engineer who advises many companies or municipalities; it is hard to see why their engineer should be shut out from advising those anxious to seek and pay for his advice.

Apart, however, from the fairness or otherwise of the competition, it is extremely improbable that consulting engineers would suffer in any way, since the persons going to the Supply Authorities' engineer would probably do without one altogether if his services were not available.

Having discussed the necessity for exercising control over consumers' installations, and having seen the possible ways in which this may be secured, it remains to consider what points it is necessary to control.

In the first place, it is important to recognise that there is an essential difference between rules necessary to secure efficient and safe wiring, and those, equally necessary, to secure a satisfactory utilisation of the public supply of electrical energy. The former are, practically speaking, independent of the system of supply; the latter will vary greatly with the nature of the system of distribution adopted by the Undertakers, and, to some extent, with the local conditions existing in the town in which the supply is given.

It is unnecessary to enter into the first question, namely that of wiring regulations. These have been the subject of investigation by all classes of those interested in the matter, and those issued by the Institution of Electrical Engineers embody the results of the latest experience and the best practice; they are sufficiently wide and liberal to admit every good system of wiring, and should be adopted for all Central Station work.

These rules call, among other things, for a certain standard of excellence to be attained by such fittings as switches, fuses, etc.; but at the present time there is no central authority, having the confidence of all concerned, that is in a position to undertake to test and certify that the specified conditions are fulfilled.

Under these circumstances, there seems no choice for those who desire the rules to be more than an empty sham but to fall back on the course already adopted in the case of water authorities, and set up their own testing station. This system was inaugurated by the author at Manchester in 1898, and although his action was met by an organised attack of considerable violence, subsequent events have shown that this did not emanate from those interested —*i.e.* manufacturers and wiring contractors—for they have welcomed the innovation and have found it beneficial to their trade, and productive of much convenience and saving of time.

For the convenience of those who may wish to adopt a system of registration, the arrangements made by the Author may be described. Switches, fuses, and similar fittings have to be submitted for approval, and are tested to see that they conform to certain specified requirements; provided they do this, they are registered, and hence there is no room for unfairness or favouritism.

Articles may either be submitted by (i) consumers (directly or through their contractors) or (ii) by manufacturers, merchants, or their agents. In the former case, the article to be actually used must be submitted, and if approved, the certificate issued will apply only to the individual article. In the latter case, the article submitted must be identical with articles of a particular pattern supplied by the applicant, and if approved, the article will be registered, and the certificate issued will apply to all articles identical with that tested. Such fittings are known as Approved Fittings, and contractors are entited to use them without individual samples being tested during the period the certificate is in force. The certificate is in force for one year from the date of issue, but may be renewed from year to year at the discretion of the City Electrical Engineer without further tests of the article. Samples of all approved articles are kept at some convenient place for inspection, and a list giving particulars of régistered articles issued from time to time. The following conditions must be fulfilled:—

(*a*) All articles submitted must be such as are actually to be used, or likely to be used, in installations to be supplied with current by the Undertakers.

(*b*) Written application for testing must be made on the official form, to be obtained at the offices of the Undertakers, and must be signed by the person submitting the sample.

(*c*) All articles must be delivered, carriage paid, at the testing station, and must be removed by the person submitting them within forty-eight hours of his receiving notice from the Undertakers to do so.

(*d*) The Undertakers will not be responsible for any damage to any article either in transport or while in their charge, nor for any loss sustained in consequence of the time which may elapse before the article is returned. All possible care and despatch will be observed.

(*e*) Each article must be clearly marked with a number and distinguishing mark.

(*f*) Each article must be accompanied by a statement of the purpose for which it is intended, and the maximum pressure and current it is intended to employ in connection with it.

(*g*) No electrical measuring instrument can be received for calibration.

Articles submitted by manufacturers, merchants, or their agents are subject to the following additional Regulations:—

(*h*) Samples must be submitted in duplicate, and both become the

absolute property of the Undertakers unless the nett selling price of the fitting exceed 10s., in which case one of the fittings will be returned to the applicant after testing, if desired.

(*j*) Each article must be marked with a trade mark or other means of permanent identification, and must be accompanied by a reference to the applicant's catalogue.

(*k*) One of the samples will be tested, and the other preserved for inspection by contractors. The one tested, if its nett selling price exceed 10s., will be returned to the applicant at his request.

(*l*) The certificate will be forfeited if any change is made in the design, size, workmanship, or material of the article, the sample of which has been approved, or if the certificate is published as an advertisement by the person to whom it is granted.

The forms of application are reproduced in Forms 9 and 10. Form A relates to single articles which are submitted for test, and are to be used at a particular installation. Form B is applicable to those articles which are used in large quantities. By submitting samples for test once for all, articles identical with them may be used, as already stated, without further application or test; this is a great convenience to contractors, and the permanent exhibition of their wares afforded to manufacturers is of great value, their goods being gratuitously brought under the notice of the very persons who will become their customers.

Certificates of approval A and B relate to the applications of corresponding letter, and certificate C is one of renewal of B. See Forms 11, 12, and 13.

To enforce the regulations as to wiring, and the registration of fittings, special powers, such as those described earlier in this chapter, are necessary. When such powers have been obtained, it is important to see that they are exercised with the strictest impartiality, the regulations drawn up in accordance with them being the same for all persons. This condition, the Author ventures to think, is entirely fulfilled in the rules given. It is to be understood, that the Author recognises no distinction between a municipality and a company as regards these regulations; they are equally necessary for both, and equally beneficial to the consumers using the supply of both.

It is those regulations affecting the supply itself which come nearest to the bye-laws contemplated in the general Act and the Provisional Order. These, as has already been pointed out, necessarily vary with the system of supply, so that a hard and fast set of rules cannot be drawn up, but the leading matters to which attention should be directed may be indicated.

It may be assumed that a low pressure multiple wire system of distribution is in use, the current being either continuous or alternating.

First, and perhaps of greatest importance, is the insulation resistance. The standard decided upon should be such as experience has shown is attained when average, thoroughly good work is carried out. On the one hand, that

FORM 9.—Application Form A for Testing.

(Name of Works here.)

FORM A. No.........

Form of Application for testing a single article to be actually used in an installation to be connected to the Corporation (*or Company's*) Circuit.

I/We ....of...............................

....hereby make application to the..............

..............................Corporation (*or Company*), and request that they will cause to be tested the accompanying...

(Here state name of article.)

....

....

which it is desired to use at..

Name of Consumer..

Address ....

Distinguishing Mark ....

The article is intended for a maximum pressure of...............volts, and a maximum current of.................amperes.

(Additional particulars, if any) ....

....

....

and I/We hereby agree to indemnify the Corporation (*or Company*), and to keep them indemnified, against any damage whatsoever that may ensue to the said article while under their charge.

Signed..

Date..........................190......

This form to be sent to the Chief Engineer,......................................

[Size 13½" by 8½". Printed on Blue paper.]

FORM 10.—Application Form B for Testing.

(Name of Works here.)

FORM B. No........

Form of Application for testing of sample representing a number of identical articles produced by Manufacturer submitting sample.

I/We ....of...............................

....hereby make application to the..............

..........................Corporation (*or Company*), and request they will cause to be tested the accompanying...

(Here state nature of Article.)

....

....

Distinguishing Mark..

Trade Mark..

Reference to Catalogue ....

The article is intended for a maximum pressure of...............volts, and a current of.................amperes.

(Additional particulars, if any.)

....

....

....

....

and I/We hereby agree that the said article and the duplicate sample submitted therewith become the sole property of the Corporation (*or Company*), to be dealt with by them as they think fit. I/We further agree that if the sample is approved, and a certificate of approval issued, I/We will not make use of such certificate for advertising purposes, and will not vary the article in any manner whatsoever.

Signed..

Date..........................190......

This form to be sent to the Chief Engineer,......................................

[Size 13½" by 8½". Printed on White paper.]

FORM 11.—Certificate A.

(Name of Works here.)

Certificate of Approval—A.

No. ....

I hereby certify that I have examined...

....

....

....

marked as follows.......................................and intended to be used at

....

....

....

....

and I hereby certify that the above article may be employed at the above address provided...

....

....

Signed...

Chief Engineer.

Date....................................190

[Size 13″ by $8\frac{1}{2}$″. Printed on Blue paper.]

FORM 12.—Certificate B.

(Name of Works here.)

Certificate of Registration—B.

No. ....

I hereby certify that I have examined...

....

....

....

marked as follows...

and bearing the trade mark...which has been submitted to me by Messrs...

of...and which is designated in their Catalogue by the number.................., and I hereby approve such article for use in installations to be supplied with electrical energy by the.................

Corporation (*or Company*), provided that...

....

....

for one year from the date of this certificate.

A duplicate sample of this article, marked as described above, is preserved at ....and can there be inspected by consumers or their contractors.

CAUTION.—This certificate will be forfeited if any change is made in the design, size, workmanship, or materials of the sample, or if this Certificate is published by the manufacturers or their agents as an advertisement.

Signed...

Chief Engineer.

Date....................................190

[Size 13″ by $8\frac{1}{2}$″. Printed on White paper.]

FORM 13.—Certificate C.

(Name of Works here.)

Form C. **No.**..........

RENEWED CERTIFICATE OF REGISTRATION.

I hereby certify that the article referred to in Certificate of Registry No............dated...................................is approved for use in installations to be supplied with electrical energy by the...............Corporation (*or Company*) for a further period of one year from the date of the present certificate.

Signed...
Chief Engineer.

Date..................................190

[Size 6½" by 8½". Printed on White paper.]

of the Board of Trade, below which if the installation fall the Undertakers are compelled to discontinue the supply, is altogether too low to adopt as a criterion of satisfactory work, while on the other, it is of no use setting up a standard which can only be attained by drying the switches and fittings with calcium chloride, and warming the ends of the cables with blow lamps. That recommended by the Institution of Electrical Engineers, viz., 10 megohms, divided by the maximum number of amperes required, answers well for most stations, but for a very large network the adoption of a somewhat higher figure is desirable in order to keep down the aggregate leakage current.

In making tests of insulation resistance, due allowance should be made for exceptional circumstances, such as wet plaster in new buildings, which causes a film of moisture to be deposited on all surfaces. The standard should not then be enforced, if the work appears good, until time has been allowed for the moisture to dry out. One or two samples may be given to show the great improvement that may take place in an installation of this kind without anything being done to it. The following are actual tests:—

Premises.	Standard required.	Insular Resistance Tests.					
		Date.	First Test.	Date.	Second Test.	Date.	Third Test.
	Megohms.		Megohms.		Megohms.		Megohms.
Block of offices, .	8	2/5/98	0·9	2/8/98	5·0	29/12/98	11·0
Shop, . . .	2	27/3/98	0·5	7/6/98	1·1	15/7/98	3 0
Vaults, . .	1·2	23/11/99	0·1	27/11/99	0·63	4/12/99	1·25

The importance of the insulation resistance of an individual installation is much less if a system of house transformers, or even if a number of small

networks, be in use than in a general distribution network, because, in the last case, even though the leak in each installation be small, the aggregate leakage current may be considerable on account of the great number of consumers connected to the network, whereas with transformers the installations are not in direct connection with the mains, and even a very bad leak will not affect them.

Of almost equal importance to the question of insulation resistance is proper provision against sudden demands of undue magnitude being made on the mains, and in the case of multiple wire distribution which we have assumed, the proper sub-division of the load in each installation, so that efficient balancing may be attained.

So far as sudden variations in load are concerned, the most fruitful source of difficulty is motors. These must be provided with arrangements which shall prevent their being started too suddenly, and switches should be so interlocked that the motors cannot be accidentally switched on without a starting resistance and so blow the main fuse. In spite of precautions being taken to prevent the electrical arrangements causing violent fluctuations of load, there is still a danger that the mechanical load may be of an intermittently heavy character, as in the case of calendering machines, wood-working plant, lithographing machinery, etc. In such cases motors should be provided with a heavy flywheel, and, if possible, the drive should be by means of a belt or ropes. The number of lamps controlled by a single switch should be limited so that an excessive load may not be thrown on and off suddenly. Large arc lamps, such as are used for photographic or stage purposes, should be provided with a starting resistance. In a large city, the demands on the system may be of great variety, and regulations may be required to cover electric welding, electrolytic processes, and electric furnaces; these involve considerable difficulties, and it may even be necessary to employ special mains where the conditions required to prevent their interfering with the general supply would be too onerous on the consumers using the processes.

With regard to the balancing of circuits, it will be well worth while to pay great attention to this matter, for faulty balancing will render it impossible to give a satisfactory supply, no matter how well everything else may be planned out. For this reason, consumers should be required to sub-divide their installations into two approximately equal circuits (four if the distribution be on the five-wire system), when a certain demand is exceeded. The limit fixed may be low without causing any appreciable inconvenience or extra expense, for in modern good wiring it has become the practice to effect the sub-division in any case, and to limit greatly the number of lamps on a single circuit. It is just as easy to connect some of these sub-circuits to another pair of mains, the only difference in cost being that due to providing two small main switches and fuses instead of one large one. Motors,

unless of very small capacity, should be supplied from the outer conductors at the maximum pressure of the network. This is an immense help as regards the balancing, the distribution for motive power being thus effected on the two-wire system, and the intermediate wires being unaffected. There is no difficulty in getting motors wound for 400 or 500 volts, and in a fairly large factory the saving in cost of wiring over 100 or 200 volts is of material advantage to the consumer. Special application has to be made to the Board of Trade for permission to supply at a pressure exceeding 250 volts, in the case of each consumer so supplied, but the assent is never refused under ordinary circumstances. A form of application devised by the Author, and accepted by the Board of Trade, is reproduced on p. 381. The special conditions usually imposed by the Board are the following:—

(1) The frame and shaft of every electric motor intended to be worked at the pressure specified in this approval (400 volts) shall be efficiently connected with earth.

(2) The electric lines forming the connections to motors, or otherwise in connection with this supply, and placed upon the aforesaid premises of the consumers shall be, as far as practicable, completely enclosed in strong metal casing efficiently connected with earth.

(3) The supply to every motor shall be controlled by means of an efficient cut-off switch, placed in such a position as to be easily handled by the person in charge of the motor, and connected so that by its means all pressure can be cut off from the motor itself, and from any regulating switch resistance or other device in connection therewith.

Efficient fuses, or other automatic cut-outs, shall also be provided, so as to protect the branch circuit on each side of every motor from excess of current.

The above mentioned switches and cut-outs shall be so enclosed and protected that there shall be no danger of any shock being obtained in the ordinary handling thereof, or of any fire being caused by their normal or abnormal action.

(4) A notice shall be fixed in a conspicuous position at every motor and switchboard in connection with this supply, forbidding unauthorised persons to touch the motors or apparatus.

Lastly, it is very important that every precaution should be taken to prevent a consumer from obtaining a shock, for, although under ordinary circumstances a low-pressure shock is quite innocuous to adults, cases have been known in which such shocks have proved fatal, while in the case of children of tender years lifelong, if not fatal, injury might be caused. For this reason, regulations should be made to provide for the enclosing with insulating material of switches, fuses, lamp terminals, etc.; while the framework of motors and heating devices should be permanently connected to earth, so that their potential may not rise through leakage from the circuit.

The Author has given much attention to the framing of regulations to

FORM 14.—Form of Application to Board of Trade.

No.........

(Title and Date of Lighting Order here.)

TO THE BOARD OF TRADE.

In accordance with Regulation 1 of the Regulations for securing the safety of the public made by the Board of Trade under the Electric Lighting Acts 1882 and 1888, I, the undersigned..
the Consumer, and we (here give name and description), *the Undertakers, hereby make application to you for your approval of a supply by the Undertakers to the Consumer of current in premises situate at*..............................
....*within the area of supply of the Undertakers, at a pressure of 400 volts (the limits of variation from this declared pressure being 380 volts and 416 volts) for the purpose of*................
....
....
....
....
....

Dated the....................*day of*.............................190......

Consumer:
Signature—
....
Address—
....
Occupation—
....

Undertakers:
....
Chief Engineer,
duly authorised to sign this application for and on behalf of the Undertakers.

[Size 13½" by 8½".]

cover the above-mentioned points, and although, as already stated, each system must have its own set of regulations, some of the more important ones may be of service as models, and they are therefore reproduced below, a note being added to each to explain its object.

Lamps, etc.—For all purposes except motors a demand up to 2½ kilowatts will be supplied from one pair of terminals, above 2½ kilowatts the consuming devices must be divided into two approximately equal circuits. In those streets in which a 100-volt supply is available, the consuming devices must be divided into two approximately equal circuits when the demand exceeds 2½ kilowatts and is below 5 kilowatts. If above 5 kilowatts they must be divided into four approximately equal circuits.

The following table shows the requirements for installations of various sizes. One 50 c.p. lamp may be taken as equivalent to two 25 c.p., or to three 16 c.p., or to six 8 c.p., and one ordinary arc lamp (500 watts) to fifteen 8 c.p. lamps:—

Installations up to 80 lamps of 8 c.p. to be on one circuit not exceeding	25 amps.	at 100	volts each
Or one circuit not exceeding	12½ ,,	200	,,
Installations between 80 lamps of 8 c.p. and 160 lamps of 8 c.p. to be on two equal circuits not exceeding .	25 ,,	100	,,
Or two equal circuits not exceeding	12½ ,,	200	,,
Installations above 160 lamps of 8 c.p. to be on four equal circuits		at 100 volts.	
Or two equal circuits.		at 200 ,,	

Motors.—Current will be supplied at 200 volts for motors absorbing not more than 2½ kilowatts—*i.e.*, 3⅓ Electrical Horse Power; above 2½ kilowatts at 400 volts. In those streets in which 100 volts is available the same rules apply, except that motors taking not more than ¾ kilowatt, or one Electrical Horse Power, will be supplied at 100 volts, if desired.

The above relate to the balancing of circuits.

Insulation of Fuse and Switch Covers.—It is essential that the covers of all fuses, switches and plugs should be of porcelain, or other non-conducting material, or of rigid metal lined with vitreous enamel, or similar insulating incombustible material. The use of asbestos for this purpose is allowed, but is not recommended. If it be used, the asbestos must be not less than $\frac{1}{16}$ in. thick. Any metal parts whatever liable to be touched by the hand must be effectually insulated from the electrical circuit. In the case of large switchboards the covers for the individual switches may be dispensed with if the whole switchboard is contained within an incombustible casing, or is placed in a chamber accessible only to some responsible person. If the cover of a fuse or switch be lost or broken it must be immediately replaced.

Lampholders.—These must be of approved design, and in the case of lamps supplied at a pressure of 200 volts there must be a porcelain bridge provided between the terminals, or such other means must be taken as to secure efficient insulation between them. In cases where lampholders are liable to be handled by a person making good contact with earth, the lampholders must be provided with porcelain or other non-conducting covers. Where lampholders are combined with switches of the form known as key sockets, the switch portion must conform in all respects to the ordinary rules for switches, and the lampholders must be provided with porcelain or other non-conducting covers.

These are directed towards preventing the danger of shock through a metallic cover getting into accidental contact with the circuit by means of a loose wire or otherwise.

Starting of Arc Lamps.—Arc lamps must be so constructed that the current flowing at the instant they are switched on does not exceed a current 80 per cent. in excess of the normal working current.

Large Arc Lamps.—Where an arc lamp when burning under normal conditions takes more than 15 amperes, and in the case of all hand-regulated arc lamps, a starting resistance must be provided so arranged that the current cannot exceed 15 amperes at starting, nor increase by greater steps than 10 amperes at a time as the resistance is cut out. The resistance must be so arranged that it can only be cut out gradually, and it is preferable that it should be continuously reduced, and not by sudden steps.

These are to prevent sudden variations of load. See also "Starting of Motors," p. 383.

Insulation Resistance.—The insulation resistance of any part of a motor which carries current, together with all leads, sliding contacts, or metal-work connected to the circuits of the motor, shall not be less than 1 megohm when the magnets, framework, and shaft of the machine are connected to earth.

Framework to be Connected to Earth.—The magnets, frame, and shaft must be permanently connected to earth by a copper conductor having a sectional area equal to

that of either of the two main conductors leading to the motor. Where these conductors exceed 10 square millimetres in sectional area, the area of the earth conductor shall be not less than 10 square millimetres, but need not be more. It is preferable that the earth connection should be made by means of a water-pipe or copper-plate buried in moist earth. Gas-pipes must on no account be used for the purpose.

Starting of Motors.—All motors in which the current passing through them can momentarily exceed 10 amperes when the motor is connected directly with the mains must be provided with a switch and starting resistance to be approved by the City Electrical Engineer, and to be such that in no case can the current through the motor when the switch is on the first contact exceed 10 amperes, or increase by greater steps than 10 amperes at a time as the starting resistance is cut out. This starting switch must be so arranged that the current can only be increased gradually. It is preferable that the resistance should be cut out continuously, and not by abrupt steps; but where steps are used the gradual increase in current may be provided for, either by arranging the switch so that it is physically impossible to move it quickly, or by providing that the circuit shall be opened automatically if the switch be moved fast.

In the case of very large motors where the above Regulation would not apply, special arrangements must be made with the City Electrical Engineer, but it will in all cases be required that the current shall increase gradually.

Cut-off Switch.—The supply to every motor must be controlled by means of an efficient double-pole cut-off switch, placed in such a position as to be easily handled by the person in charge of the motor, and connected so that by its means all pressure can be cut off from the motor itself and from any regulating switch, resistance, or other device in connection therewith, and it must be so arranged that it interlocks with the starting resistance in such a manner that the double-pole switch can be taken off when the starting switch is in any position, but cannot be put on again until the starting switch is in the position which leaves all resistance in circuit.

The switch referred to in this Regulation is required in addition to the ordinary main switch, except in cases where the motor is fixed within 15 feet of the entrance of the Corporation service, in which case the switch referred to in this Regulation may take the place of the main switch.

Cut-outs.—An efficient fuse or other automatic cut-out must be provided on each pole, so as to efficiently protect the branch circuit to every motor from excess of current. Two separate single-pole cut-outs must in all cases be used, and it is preferable in the case of 400-volt motors that a magnetic blow-out, or some equivalent device for extinguishing the arc, should be provided.

Resistances.—All resistances for starting and regulation of motors must be of sufficient size to safely carry the maximum current which can pass through them for the time during which it normally flows, and they must be mounted on incombustible bases, and so fixed that they cannot by conducted or radiant heat set fire to any material in their vicinity. They must further be completely enclosed by incombustible material, placed at such a distance from the resistance that it cannot become dangerously hot, and so arranged as to entirely preclude the possibility of accidental contact with the resistance. In the case of 400-volt motors the casing must be metallic, and must be connected to earth.

Brush Rockers.—The brush rockers on motors must be so arranged that they cannot be moved so as to bring either conductor into contact with the framework of the motor.

Terminals of 400-volt Motors.—The terminals of 400-volt motors must be so guarded that it is impossible for them to be accidentally touched, and provision must be made to avoid the possibility of their being accidentally short-circuited.

Enclosed Motors.—In situations where motors are fixed in the presence of explosive dust or gas, the motor should be completely enclosed in metallic casing, and arrangements should be made for efficient ventilation of such casing by means of air drawn from the outside of the building.

Conductors for 400-volt Motors.—In the case of motors supplied at a pressure of 400 volts, the conductors must be enclosed in strong metal casing, efficiently connected with earth. The conductors must be insulated first with a layer of pure rubber, then with a

layer of vulcanised rubber of approved thickness, and the whole must be protected with a layer of braiding or taping rendered impervious to moisture.

In no case must the insulation resistance be less than 2500 megohms per mile when tested after one minute's electrification, the coil being immersed in water at the time of test, and for twenty-four hours immediately preceding.

These ten regulations are given in full as they cover most of the points that require attention, and embody the requirements of the Board of Trade with respect to motors wound for pressures of 400 or 500 volts.

There are a number of details in connection with the supply of consumers which may conveniently be referred to here.

The official regulations issued by the Undertakers should emphatically repudiate all responsibility beyond the terminals of their service lines, and should make clear that the test made by them of the consumer's installation is carried out for their own purposes, and implies no warranty that the installation is properly wired.

Next should follow a declaration of the pressure or pressures of supply.

The question of service lines often presents considerable difficulties when a building is occupied by several tenants, it often being difficult to obtain permission to carry conductors for one tenant through the tenement of another.

In this connection, it is well to note that the Undertakers have fulfilled their obligations when they have brought their service lines up to the boundary wall of the building, and as a matter of fact, they have no right to enter on the landlord's property. On the other hand, it is to their advantage to facilitate the taking of their supply in all cases, and, as a matter of policy, it is well, when the landlord or occupier raises no difficulty, to cut the necessary hole through the wall and take their service into the building free of charge, fixing their main fuse as near as possible to the point of entry. In the event of any difficulty being raised, they should at once take refuge in their strict legal rights, and throw on the consumer the onus of getting all necessary permissions and of cutting into the wall. On no account should the Undertakers allow anyone but their own officials to run their service lines.

A large building containing many offices let out to numerous tenants frequently presents difficulties. The best way to deal with the matter is to get the landlord to put in the main wires to each floor, leaving the tenant to wire his own offices, and, in some cases, landlords are wise enough to see the advantage to themselves of adopting this course and augmenting the value of their property, while saving its being damaged by a great number of separate casings being run down to the basement.

It is the Author's practice to give the option of three courses in such a case, these being defined as follows:—

(*a*) The conductors may be run from the premises of each tenant to some convenient point in the building, to be approved by the Chief Engineer. In this case a separate main fuse for each tenant and a separate meter will be provided and fixed by the Corporation (*or Company*) free of charge, and the tenants'

will be regarded as separate consumers dealing directly with the Corporation (*or Compauy*), and each must fill up an application form for his own lamps. A double-pole main switch and main fuses must be provided and fixed by each tenant, as in the case of ordinary consumers.

(*b*) Main wires may be run by the landlord of the building from the entrance of the Corporation (*or Company's*) service main to various convenient points in the building. At the termination of these main wires the Corporation (*or Company*) will fix distribution boxes, and the conductors from the premises of each consumer may be run to these, the supply being then given on the same terms and under the same conditions as are enumerated in paragraph (*a*) above. Where this course is adopted, the landlord of the building must give the following undertaking that the main wires will not be tapped at any point other than where the Corporation (*or Company's*) distributing boxes are fixed.

To the Electricity Department,
.... Corporation (*or Company*).

I..of...................................being a landlord of the premises situated at...hereby apply to the...Corporation (*or Company*) to provide and fix distribution boxes at suitable points in these premises, and I will provide the necessary cables to connect these distribution boxes to the .... main fuse fixed at the termination of their service lines. I undertake that no connections of any kind shall be made to these cables except where they are attached to the distribution boxes, and I hereby agree to indemnify the ...., and to keep them indemnified against all losses that they may sustain through the connection, surreptitious or otherwise, of consuming devices to these cables, or in any other manner than through the distribution boxes.

(*c*) The building, as a whole, may be wired, and the conductors of the several consumers tapped off wherever desired. In this case a double-pole switch and main fuses must be provided and fixed by each consumer where his conductors branch off from the main wiring of the building, and the meter will be provided and fixed on the consumer's premises by the Corporation (*or Company*); a master meter will also be fixed for the whole building. The Corporation (*or Company*) charge rent for all sub-meters fixed, and will send their meter reader to read them, but the account will be rendered on the reading of the master meter only, the tenants not being recognised as separate consumers. In this case the proprietor of the building must apply for the whole number of lamps required by the consumers. He will be furnished with the readings of the meters, but he must himself recover from the tenants the various amounts for the quantity consumed by them, the Corporation (*or Company*) accepting no responsibility in the matter whatever.

Meters should be fixed so as to adjoin the main fuses; if, as is often the case, the consumer desires them to be fixed at some distant point, he should be required to have the connection made by means of cables either armoured or enclosed in an iron pipe so as to diminish the risk of their being fraudulently or accidentally tapped before the meter is reached.

Consumers should be required to give notice of alterations in their installations, and no work that is incomplete or of a temporary nature should be allowed unless the engineer to the Undertakers has specially sanctioned it.

If not provided by the Undertakers, the consumer should be required to fix a main switch within three feet of the meter so as to enable the whole installation to be cut off in case of need.

CHAPTER XXXII.

GENERAL ORGANISATION OF A CENTRAL STATION.

The organisation of an electrical undertaking calls for much care and thought, for its success depends greatly on the way in which it is managed. There is, doubtless, room for considerable difference of opinion as to the best method to adopt, and the system required for a large concern necessarily differs materially from that for a small one; while the arrangements will depend in some measure on whether the undertaking is municipal or otherwise.

There will be broad lines, however, which should be followed in all cases, and it is the Author's intention to describe in detail what he considers suitable for a scheme of considerable magnitude, it being an easy matter, by excision and coalescence, to adapt the organisation described to smaller concerns.

The first broad principle is that, subject to the Board of Directors, or the Municipal Committee, as the case may be, the supreme authority must be vested in an engineer, for the nature of the work is such that, whether it be regarded from the theoretical engineering side, from the side of practical operation, or from the purely commercial side, it will be found that abstract science and technical knowledge enter into nearly every question that arises.

This contention necessarily presupposes that the engineer has commercial knowledge and aptitude, but this is a necessary attribute of every successful engineer; a mere abstract scientist or enthusiastic visionary will certainly lead his company or municipality into ruin, be he never so well controlled by a commercial man without technical knowledge, while a good engineer will only be hampered and galled by the restraint imposed.

The functions of an engineer having charge of a central station undertaking are consulting and managerial. All new works must either be planned by him, or under his immediate supervision, and he must be fully cognisant of the work of every single department, the responsible head of each being in close and direct touch with him; in this way, and in this way only, can the various branches of the work be harmonised and made to march in conformity with one another.

No matter how large, or how important, any one department may be, its head must not work independently of the Chief Engineer; the latter must make it his business to be personally acquainted with the work of each of his immediate subordinates, and must not shrink from going into fully detailed work at times. He must be no mere figure-head or puppet, but must make his influence and personality felt in every department, guiding its work and shaping its policy in all matters.

Let it be clearly understood, however, that he must strictly confine his dealings to the heads of the departments, and must, on no account, go over their heads or interfere in any shape or way with their subordinates for whose work they are responsible to him. It is the Chief Engineer's business to uphold his staff and make their authority respected by those under them, while among the various members of his staff he must promote good feeling and loyalty to the undertaking as a whole, securing a healthy spirit of emulation between departments without provoking jealousy.

While following the above policy, the right to appeal to the Chief Engineer should be accorded to every employé, even the humblest; for there is always the possibility of injustice being done by those least suspected. At the same time, the men must be given clearly to understand that the abuse of this privilege will lead to serious results for them, and that frivolous or malicious complaints will involve their dismissal.

The most appropriate official title for the Chief Engineer is 'Engineer and Manager,' if a Company be the Undertakers, or 'City (or Borough) Electrical Engineer,' in the case of Municipal ownership. Within the works, however, it is convenient to refer to him as the Chief Engineer, and he will be thus denominated in what follows.

We have now to consider the nature of the officials immediately responsible to him. These are, primarily, the Second Engineer, the Secretary, the Chief Works Clerk and the Chief Engineer's Private Secretary. The necessity for a Second Engineer arises from the fact that there must be some person to take control in the absence of the Chief Engineer. Were it not for this, it would be better to omit this office altogether, but since this is not practicable, the Second Engineer should assist the Chief generally, dealing ordinarily only with purely engineering matters, but assuming full control when he is away. It is not advisable that communications from the heads of the various engineering departments should come through the Second Engineer, but direct to the Chief, he deputing such work to the Second Engineer from time to time as he considers desirable.

The heads of the departments referred to who are, in a sense, secondarily responsible to the Chief are the Electrical Engineer, Steam Engineer, Mechanical Engineer (one of each class for each generating station), the Mains Engineer, the Distributing Station Engineer (if the system involve

sub-stations), the Installation Inspector, the Street Lighting Inspector, the Head of the Standardising Department, the Chief Draughtsman.

Each of the officials responsible to the Chief Engineer has his own staff divided in some cases into distinct sub-departments. The whole arrangement is shown in diagrammatic form in fig. 135 opposite. The working of each department will be described in detail in succeeding chapters. In this it will be sufficient to describe the general scheme.

In the first place it must be pointed out that, although the various departments are distinct and self-contained, yet they are mutually dependent; and the work of one, though not exactly overlapping that of another, is complementary to it. This is the only feasible way of avoiding a considerable amount of duplication of work and staff; and at the same time one department forms a very efficient and useful check on another.

The first main division is into engineering and clerical departments.

The former comprises the following branches:—

The Generating Stations wherein the whole of the energy is generated and sent into the mains, the plant being maintained in repair by the staff.

Next the Mains Department, by the staff of which the whole canalisation is constructed and maintained, and the energy supplied by the generating station is received and passed on into the consumers' premises.

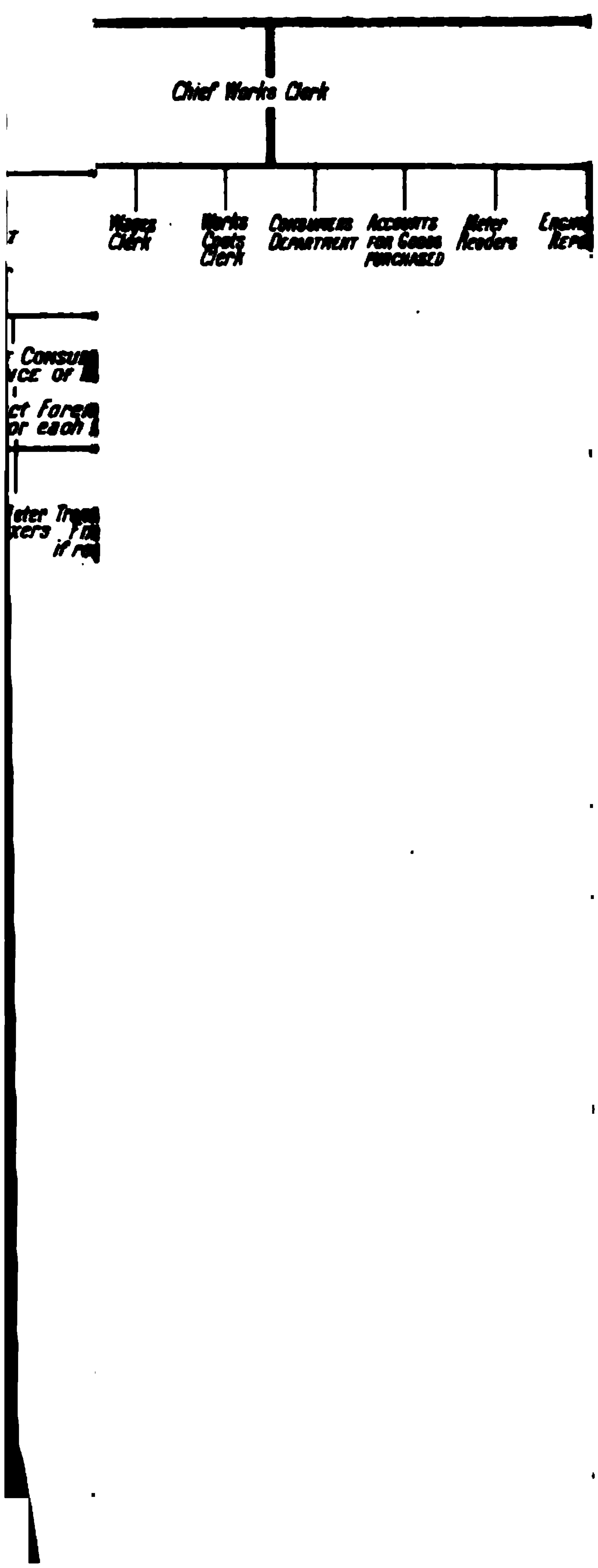
The Installation Department then steps in, sees that the consumers' wiring and fittings are in order to receive the energy, and maintains the measuring and controlling apparatus.

Closely interwoven with the work of all three, is the work of the Drawing Office; in this is planned out all new work in the Generating Station and in the Mains Department, while all the records of the output and working of the Generating Station are plotted down and put into shape, and, as regards the Mains Department, the work done is surveyed and recorded, material used checked, and the mains tested electrically. The Installation Department comes into relation with the Drawing Office in connection with the consumers' appliances; the extent and distribution of their demand being recorded, and an accurate account kept of the balancing of the circuits. The Drawing Office may thus be looked upon as the originating and recording authority, the other three departments being the executive ones.

When Sub-stations are employed, the department dealing with them comes chiefly into relationship with the Generating Station with which its work is intimately related.

In the event of Street Lighting being undertaken, the Mains Department carries out the constructive work, laying the mains and erecting the poles, lamps, and other apparatus.

Inasmuch as no work can be carried out without clerical labour, the department of the Chief Works Clerk is introduced. This takes cognisance of all clerical work attached to the engineering part of the work, and is



Chief Works Clerk
Wages Clerk
Works Costs Clerk
Consumers Department
Accounts for Goods Purchased
Meter Readers

brought into close and intimate contact with every department. Thus it orders, receives, and issues the stores, keeps account of the workmen's time, makes out Works Orders, ascertains the cost of the works carried out under the orders, checks accounts for goods supplied, and prepares certificates for payment in respect of large contracts, reads consumers' meters, and prepares all material for the charging of accounts, and records all particulars relating to consumers' installations, and, finally, takes charge of all reports on engineering matters, and prepares, from the crude form in which they are presented, digests and summarised reports showing the working of the whole engineering portion of the undertaking.

The clerical department proper comprises the Private Secretary and the Secretary. The former has charge of all correspondence, opening letters, distributing them to their proper departments, filing away correspondence, and, by means of the reporting and typewriting staff, answering all letters. In addition to this, all the Chief Engineer's special work, reports, specifications, etc., are prepared, carefully read over, and checked.

The Secretary's department obtains tenders for stores and arranges for the purchase of everything required, receives all accounts for goods and pays them after they have been checked by the engineering clerical staff and certified by the Chief Engineer, pays the wages of workmen and salaries of officials on the authority of the Chief Engineer, renders accounts to consumers on the data supplied by the engineering clerical staff, receives payment for them, and keeps the whole of the financial accounts, attending to the issue of fresh capital, payment of dividend, etc., or, if a municipality, the raising of loans, payment of interest, sinking fund, etc. The Secretary further attends to the enquiries of consumers, receiving their applications and investigating their financial standing before passing on the application to the works staff. Legal and Parliamentary work is also dealt with by the same department. In many municipalities, a portion of the Secretary's work here set out will be dealt with by the City Treasurer and Town Clerk.

Enough has been said to show the general scheme; the amount of detail in each department is, of course, very considerable. One primary rule may, however, be mentioned here, as it is common to all executive departments, namely, that no work may on any account be carried out unless a written Works Order has been issued on the authority of the Chief Engineer, specifying the nature of the work to be done.

Each Works Order has a number to identify it, supplemented by a letter indicating the department, and all material and labour is booked to this number. When the work is completed, the cost is ascertained, the degree of accuracy attained being very high if the system is properly carried out, and the cost is entered up on the Works Order, which is then filed away for reference.

These Works Orders are issued for both construction and maintenance,

among the latter being a number of general Works Orders running for a given period, usually a year. These cover the ordinary maintenance of all plant as well as certain little odd jobs, etc., the object being to provide a definite number to which time and material may be booked, so that every hour of labour and all stores may be accounted for.

Another rule applicable to all executive departments, is the use of time sheets by the workmen.

Every man paid hourly should have a time sheet on which is specified his number, name, department, the date, the nature of the work he has been engaged on, and the time he has been at work on a particular job, distinguishing between ordinary and overtime. The sheet is handed in by the man to his foreman who examines it, and initials it if correct, his signature authorising overtime if worked. The sheet is then passed on to the timekeeper who checks and enters up the time, initialing the sheet and then handing it to the Works Wages Clerk, who examines and initials it. Such a sheet is shown in Form 15.

FORM 15.—Daily Time Sheet.

(Name of Works here.)

DAILY TIME SHEET.

Date.............................190

Name..................................... *No*......... *Department*......................................

W. O. No.	WHERE AT WORK.	DESCRIPTION OF WORK.	TIME.					
			ORDINARY.			OVERTIME.		
			From.	To.	Hours.	From.	To.	Hours.
							Total....	

.... *Examined*............................ ....

Foreman. *Timekeeper.*

[Size 5¼″ by 8¼″. Printed on blue paper.]

For men paid weekly or working on shifts, a time sheet of a different kind is required. On this is set forth, as before, the workman's number, name, department and date. In addition to this, the number of hours of ordinary time that he has worked. If he has worked overtime, the sheet

provides spaces for the nature of the extra work and the time occupied. This time sheet passes through the same routine as the daily one. A weekly time sheet is shown in Form 16.

FORM 16.—Weekly Time Sheet.

(Name of Works here.)

WEEKLY TIME SHEET. *Week ending*..............................*190*

Name.. *Department*....................................

ORDINARY TIME............*HOURS.*

No............ **PARTICULARS OF OVERTIME.**

Date.	Nature of Work.	From	To	Hours.
			Overtime..	
			Ordinary..	
			Total.....	

.... *Examined*............................ ....

Engineer. *Timekeeper.*

[Size $5\frac{1}{4}''$ by $8\frac{1}{4}''$. Printed on white paper.]

It is convenient to adopt different colours to distinguish between daily and weekly sheets, and between different departments.

CHAPTER XXXIII.

THE GENERATING STATION.

THIS, as has been seen, is so arranged that the work is divided between an Electrical, a Mechanical, and a Steam Engineer. Now it is perfectly obvious that, so far as the actual running is concerned, only one man can be in charge, for the men cannot obey more than one master, nor can an emergency be dealt with by several leaders at once. Hence the Mechanical and Steam Engineers look after the generating and boiler plant, respectively, when it is at rest, the Electrical Engineer when it is running. The duty of the two former is to have their respective plants in efficient running order, and ready at the Electrical Engineer's call when required by him. Once started, the plant is absolutely under his control. Besides the running, the Electrical Engineer maintains the switch-gear and instruments, and advises the Mechanical Engineer as to the purely electrical repairs required by the plant, looking after the electrical craftsmen.

The Steam Engineer is responsible for the cleaning and upkeep of all boilers, stokers, coal-conveying plant, steam pipes, feed pipes, valves, pumps, blast fans, flues, chimneys, economisers, and all accessory plant connected with the above. He takes samples of coal as often as he considers it necessary, and sends them to the chemist for examination; he watches the combustion and sees that the fuel is burnt under the most advantageous conditions, taking samples of the flue gases for analysis by the chemist, and watches the temperatures attained at important points. He also sees that all coal is accurately weighed.

In all these matters he acts on his own initiative, and reports direct to the Chief, but he also has charge of the leading stoker, and his stokers and coal trimmers or labourers, of the men who look after the coal-conveying and weighing plant, and of the pump men. All these men work under his instructions, and he himself, so far as their operations are concerned, under the Electrical Engineer, this work being essentially part of the running.

The leading stoker is foreman over the other stokers on his shift and over their labourers. If hand firing be employed, a number of the latter will be coal trimmers. The work of the men under the leading stoker

consists in attending to the feeding of the furnaces, removal of ashes, cleaning of fires, the connecting and disconnecting of the boilers to and from the ranges, the regulation of the feed water, and the cleaning of the exterior of the boilers, economisers and accessories, and of the boiler house generally. The cleaning, packing and working of the feed pumps and injectors is assigned to a special pump man.

The boiler cleaners have their own foreman, and keep the interior of the boilers free from scale, and the flues from soot.

The leading crane man looks after the crane-drivers and men attending to the coal-conveying apparatus.

Such repairs as can be effected by the Steam Engineer's own staff are carried out by them, heavier repairs he hands over to the Mechanical Engineer, whose men then actually do the work under his instructions, he consulting with the Steam Engineer as to what is required and the way in which it is to be done.

The Mechanical Engineer is primarily responsible for the steam engines in the Generating Station. He maintains them in efficient condition, taking up bearings, maintaining packings, setting valves, regularly indicating the engines, making all joints on the engine side of the engine stop valve, keeping all valves in order, maintaining condensing plant, pumps, etc., and water-cooling apparatus, if used. He periodically thoroughly overhauls every piece of machinery. He also attends to the mechanical portions of the dynamo machines, and generally maintains all mechanism.

So far as the above work is concerned, he is independent of the Electrical Engineer, and has his own staff, comprising foreman fitters, fitters and their labourers, smiths, strikers, etc. He has a repairing shop, with all necessary tools for effecting repairs up to a given magnitude, and in this tool shop he reigns supreme.

Once an engine or machine is running, he must not interfere with it, even though the Electrical Engineer should see fit to destroy it, for it may often be preferable to badly damage the plant rather than interrupt the supply. While the plant is running, however, it is necessary that the Mechanical Engineer should watch it and test any points he thinks necessary, including, of course, the indication of the engines, the Electrical Engineer giving all facilities compatible with the exigencies of the supply.

The Electrical Engineer is immediately in charge of the Shift Engineers, and transmits his orders through them to the men running the plant. Each Shift Engineer takes charge of the running of the plant during a shift, and, in the absence of the Electrical Engineer, takes his place. These men must be well trained electrical engineers, and of the same type as the Electrical Engineer, but younger; they are in fact his understudies.

Under the Shift Engineers are the switchmen who attend to the switchboard and are skilled electrical workmen. They are supplemented by

youths, preferably pupils, who read all the measuring instruments, change sheets on recording instruments, and obtain the information for the log sheets which they keep.

In addition to these electrical men, are the dynamo attendants. These look after the brushes, collectors, and commutators of the generators and exciters and also after all motors wherever used in the station, the trimming of the station arc lamps and the lighting of the works generally.

Also under the Shift Engineers, is the leading driver in whose charge are the drivers, greasers and cleaners. The leading driver is preferably a marine engineer who has filled a 'chief engineer's' berth at sea; the drivers may with advantage be, partly, men who have served their time as fitters, partly, men who have driven express locomotives, and partly, men who have been in the works a long time and have worked their way up from greasers. The first are handy for minor repairs, and in the summer can be found work at overhauling by the Mechanical Engineer; the second are usually men of good nerve, and can be relied upon not to shirk driving their engines in any emergency that may arise; while the third are presumably steady men, and are intimately acquainted with the particular plant in the station, and with the works routine. The greasers are ordinary labourers, preferably men who have been used to machinery.

The cleaning staff is best kept distinct, one set of men having certain engines assigned to them so as to secure a spirit of emulation.

The Shift Engineers thus look after the running of the plant, the recording of the work done and the maintenance of the plant and engine-room generally in a clean and smart condition, besides controlling the boiler house through the Steam Engineer when he is on duty, or directly in his absence.

Besides the Shift Engineers, the Electrical Engineer has charge of the upkeep of the purely electrical portion of the plant, having armature winders and electrical fitters under his control.

There is, of necessity, a certain amount of borrowing of men. Thus, both the Mechanical Engineer and the Steam Engineer will borrow drivers and greasers for minor repairs, packing, joint-making, etc., while heavy electrical repairs will be done by the Mechanical Engineer's staff under the Electrical Engineer's supervision.

So much for the organisation of the staff. We have now to consider the way in which the work is carried out.

First as regards the Electrical Engineer's work. The bulk of this is routine, most of his men are paid weekly, and there is practically no constructive work. The electrical repairing staff is very small, and most of its work can be covered by a few general Works Orders, with separate Works Orders for such specific work as is undertaken from time to time, *e.g.* the manufacture of new switches, repair of special motors, etc.

The most important document with which the Electrical Engineer has

to deal is the log sheet. This will necessarily vary greatly with the station, but in all, two main things have to be ascertained, namely, the output and the particulars of the plant running. It will be found convenient to have two separate sheets for those two purposes, and to record only what is really essential.

As far as the output is concerned, the sheet must show the rate of output from each machine, the distribution of the load on the various feeders, the total quantity of energy sent out into the mains, the water consumed, and any other information that can be obtained shift by shift. As an example of such a sheet the one devised by the Author for Manchester is reproduced in Form 17.

As regards the log of plant running, the particulars desired are the exact time that each generator has run, each boiler been fired, and each auxiliary machine used. The most convenient and graphic method of showing this is by an adaptation of the method used by geologists for showing the range in time of fossils, *i.e.* a column is devoted to each machine and all the columns are ruled off with equal intervals of time for the twenty-four hours. A line drawn from the time the machine started to the time it stopped shows at a glance how long it has been running and at what period of the day. The sheet devised by the Author for Manchester is reproduced in Form 18, as shown opposite p. 396.

A separate sheet for the electrical energy used on the works will be found desirable, since there is no object in ascertaining this more frequently than once a day, or even less often. This is merely a record of the readings of the various meters controlling the lighting and power circuits; such a sheet is easily prepared for any station.

Recording instruments are best used for keeping a log of the pressure and of the leakage from the mains, and of the steam pressure, as any variation is abnormal, and, therefore, a continuous and automatic record is essential. The sheets from these instruments should have as open a scale as possible especially as regards time, and they should either be in continuous rolls, or the sheets should run for 24 hours. These will be regularly changed by the same persons who keep the log sheets.

The Electrical Engineer should also keep a diary in which anything unusual is noted. Incidents of special or urgent importance should, of course, be instantly reported to the Chief, but, ordinarily, the events of the week should be embodied in a weekly report made up from the diary.

The Steam Engineer will not need log sheets, as his plant is dealt with in the plant output sheet, but recording instruments showing the degree of vacuum or pressure attained by the draught, the temperature of the flue gases at certain points, and of the water entering and leaving the economisers will be of great assistance; and whether the sheets be changed by the

MANCHESTER CORPORATION ELECTRIC WORKS (Dickinson Street Generating Station).

DAILY LOG OF OUTPUT.

__________ *day the* __________ *1*

	READINGS OF GENERATOR AMMETERS.														READINGS OF FEEDER AMMETERS.																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Portland Street.	Mosley Street.	Spring Gardens.	John Dalton St.	Oldham Street.	Cross Street.	Town Hall.	Peter Street.	All Saints'.	Nelson Street.	Gt. Jackson St.	Church Street.	Shudehill.	Fennel Street.	Reference Library.	St. Mary's Gate.			Distributor.	Distributor.
a.m.																																		
12.30																																		
1.0																																		
1.30																																		
2.0																																		
2.30																																		
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p.m.																																		
12.30																																		
1.0																																		
1.30																																		
2.0																																		
2.30																																		
3.0																																		
3.30																																		
4.0																																		
4.30																																		
5.0																																		
5.30																																		
6.0																																		
6.30																																		
7.0																																		
7.30																																		
8.0																																		
8.30																																		
9.0																																		
9.30																																		

READINGS OF WATT-HOUR METERS.

No.	Reading.	Reading.	Difference	Reading.	Difference	Reading.	Difference	Total Output.
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
				Total Output				

READINGS OF WATER METERS.

	Reading.	Reading.	Difference.	Reading.	Difference.	Reading.	Difference.	Total Consumption.
1								
2								

Total Water= ______

FORM 19.—Engine Repair Book.

ENGINE REPAIRS

Date	CAUSE OF DEFECT	NATURE OF REPAIRS	MATERIALS		MEN				TOTAL COST
			Particulars	Cost	No.	Description	Hours	Cost	

[Size of opening 15″ by 18⅛″.] This shows the open folio—two pages facing each other

Electrical Engineer's staff, or by that of the Mechanical Engineer, they should at all events pass through the latter's hands.

It will be necessary for him to carefully check all particulars as to the material used and the time expended by his staff, so that both may be accurately allocated to their proper Works Order numbers. These particulars are afterwards entered up by the works clerical staff in a book, which may be conveniently reproduced here (see Form 19, p. 397).

In this, a separate page, or group of pages, is assigned to each boiler or other important piece of plant, from which, as will be seen by inspection, the exact cost of all repairs can be learned.

Books will be kept by the Steam Engineer showing the dates of overhauling and cleaning boilers, cleaning out main flues, etc., and also giving particulars of samples of gases, coal, etc., so that they may be identified when the chemist reports upon them. Such books are easily prepared, and need not be given in detail.

The Steam Engineer will present a weekly report to the Chief, describing broadly the ordinary work done, and in detail any experiments made.

The Mechanical Engineer will follow practically the same course as the Steam Engineer, and particulars of the repairs carried out by him will be entered up in precisely similar books devoted to engines and dynamos.

The salaries to be paid to the various officials vary between wide limits, according to the importance of the station. For a large one, fair salaries would be as follows:—

Electrical engineer,	£300	to	£500
Mechanical engineer,	250	,,	350
Steam engineer,	200	,,	300
Shift engineers,	200	,,	300

The wages of the workmen will be practically independent of the size of the station, but will vary somewhat in different parts of the country. The following rates are applicable to the Lancashire district:—

	£	s.	d.		£	s.	d.	
Switchmen,	1	15	0	to	2	5	0	per week
Dynamo attendants,	1	8	0	,,	1	15	0	,,
Leading driver,	2	0	0	,,	2	5	0	,,
Drivers,	1	10	0	,,	1	18	0	,,
Greasers,	1	0	0	,,	1	4	0	,,
Boy greasers,	0	10	0	,,	0	18	0	,,
Cleaners,	0	15	0	,,	1	4	0	,,
Leading stoker,	1	10	0	,,	1	16	0	,,
Stokers,	1	8	0	,,	1	14	0	,,
Coal trimmer or labourer,	1	0	0	,,	1	5	0	,,
Pump men,	1	2	0	,,	1	6	0	,,
Crane drivers,	1	10	0	,,	1	16	0	,,
Boiler cleaners,	1	0	0	,,	1	6	0	,,
Foreman fitter,	2	0	0	,,	2	10	0	,,
Fitters,	1	16	0	,,	2	0	0	,,
Fitters' labourers,	1	2	0	,,	1	4	0	,,

	£	s.	d.		£	s.	d.	
Smiths,	1	16	0	to	2	0	0	per week
Strikers,	1	2	0	,,	1	4	0	,,
Armature winders,	1	16	0	,,	2	0	0	,,
Electrical fitters,	1	16	0	,,	2	0	0	,,

The custom as to payment for overtime varies in different stations. For fitters, the union rules of the Amalgamated Society of Engineers are in force; for others, for the first two hours worked, each hour is counted as one and a quarter; after this, and up to the time of starting on the next day, each hour worked is reckoned as one and a half, while for Sunday work, each hour worked counts as two.

CHAPTER XXXIV.

THE MAINS DEPARTMENT.

THE work of the Mains Department at once falls into two chief divisions, *viz.*: constructive work, or the laying of new mains; and maintenance, or the keeping in repair those already laid.

In the first stage of the undertaking, the constructive work will probably be done by a contractor, but after the first instalment, it is far better, except in the case of very small concerns, to have a staff of men in the employ of the Undertakers to lay all mains and keep them in repair. By having a permanent staff to lay all mains, the men become familiar with them, and the work of jointing on services is thereby simplified, while faults are more likely to be quickly found, because weak places are known, and the locality of the mischief suspected. The work is much more likely to be well done, no one having any interest in scamping it; on the contrary, the Nemesis of bad work, in the shape of faults, acts as a powerful deterrent. The saving in cost is very material, and, in itself, is sufficient to justify the course. In the case of a municipally-owned undertaking, there is the further strong incentive, that the control of the streets is retained absolutely in the hands of the local authority.

It cannot be too strongly insisted that this department is one of the most important of all, if not the chief. The capital spent on mains represents some 35 per cent. of the total expenditure; the mains cannot be duplicated, and, hence, the supply to the consumers connected to them is wholly dependent on good workmanship in the first instance; and this is to be secured only by skilful design and keen watchfulness during construction, for, once the ground is filled in, there is no further opportunity for examination. Again, the failure of a main may disorganise the whole supply, and make all the elaborate duplication of parts and care in the Generating Station of none effect. What can be said strong enough, then, of the folly of entrusting the work to a pupil or improver, or to an assistant at £2 or £3 per week? The work calls for skill, training, judgment, watchfulness, and the ability to look after a class of workmen notoriously difficult to manage, and the salary should be commensurate with the

attainments sought, and should be of the same order as that paid to the engineers in the Generating Station, say from £400 to £500 per annum.

For the laying of new mains, the following staff will be required, the number of gangs depending on the amount of work to be done, and the time available for carrying it out.

Each gang will consist of excavators to open the ground, skilled labourers to lay the pipes or troughing, if cable be employed, or concreters and plasterers if bare strip is being laid, one or more masons to make good the flagging, a bricklayer to build junction boxes or transformer pits, cable runners or strip runners, and, if the solid system be used, bitumen men.

A word as to the class of men to be desired. For excavating, only trained navvies should be engaged; the work is exceedingly arduous, and, unless a man has been brought up to it, he is worth little, and finds the labour killing. It will be noticed that a number of different trades are employed, and it is wise to respect the various trades unions and not to attempt to make a man play many parts. It may be worth noting here that, although in the building trade there is a sharp distinction drawn between plasterers of floors and plasterers of walls, neither class ever doing the work of the other, yet in culvert work the vertical portions do not count as walls, and all should be done by the men who plaster or 'float' floors.

In charge of all these men will be a 'ganger.' Practically everything depends on this man as far as the good behaviour of the workmen is concerned, and the utmost care should be taken to secure steady, trustworthy men. Among the most satisfactory are time-expired naval petty officers, preferably torpedo men. They are men of good character, with a pension to lose, they are used to enforcing and respecting discipline, and they have a very fair electrical knowledge. A fair wage for them is from 32s. to 35s. per week. For the tradesmen, there are, of course, ordinary union rates; while, for ordinary labourers, 5d. per hour is usual, 5½d. for the better ones, and 6d. for the 'skilled' labourers.

Over the gangers will be walking foremen; each of these will have three or four gangers under his charge according to their nearness together, and his duty is to see them from time to time during the day, watching to see that they do their duty, and settling any points of difficulty that arise in the work. These men are best drawn from the ranks of the gangers, and should be paid 40s. to 50s. per week.

For the maintenance of the mains when laid, and for the laying of services, and all purely electrical work such as jointing, fixing of disconnecting boxes, etc., it is convenient to divide the area up into a number of districts, each in charge of a foreman who will have his own jointers, plumbers, meter fixers, transformer fixers, and junction box cleaners. The

only drawback to this is, that the work may not be evenly distributed among the various districts, but this is easily got over by giving each district foreman a minimum number of men, and making up another set of men attached, say, to the central district, who can be lent to whichever district happens to be most pressed.

The district foreman has a very responsible berth, and must be a man of good electrical knowledge and experience. He is resident in his district, and has to make himself thoroughly acquainted with everything appertaining to the mains therein. When new mains are being laid, he must watch the job from day to day so as to be cognisant of all details; and if he sees anything amiss must report it to the walking foreman. He superintends the jointing and connecting up of the mains, their preparation for testing, and their final connection to the supply. He fixes the position of the services for new consumers, and superintends the whole of the work of connecting them to the mains. In the case of a fault he at once proceeds to the scene of the accident, and gives notice to the breakdown gang. Suitable wages are from £2 to £3 per week.

The service men cut through the walls of the consumer's premises, make the necessary excavations, and run the pipe or troughing, afterwards making all good. These men are best drawn from the labourers on the main-laying gangs, the most intelligent men being selected, and paid 5½d. to 6d. per hour.

The jointers must be first-class electrically trained men. Their work is to measure up the length of service main required, run it to the desired points, make the joints on to the mains, and leave everything secure for the service men to fill in the ground and make good the surface.

When new mains are being laid, they have to make all joints, fix and connect up disconnection boxes, assist at the testing of the mains, and, generally, attend to all electrical work on them. In the event of a fault they make all required disconnections. They also maintain all junction-box apparatus in good order, and see that the ends of the cables are kept clean and well insulated.

It will generally be found that jointers have to be trained to perform their duties in any particular station, but occasionally experienced men can be obtained. If not, the most promising raw material will be found in ordinary wiremen, or jointers from cable factories, though, on the whole, the former are preferable. Jointers' wages are from 8d. to 9d. per hour.

Plumbers are only required when lead-covered cables are employed; they are, of course, paid ordinary union wages.

The jointers' responsibility ends when they have brought the service lines into the building, and have left the ends securely fixed to the terminals of the main fuses, which fuses are fixed by them. From this point the work is taken in hand by the meter fixer, who, in a low pressure

supply, fixes the main fuses, meter, maximum recorder, if used, and leaves everything ready for the inspector to put in the main fuses and turn on the supply. If a house transformer system is in use he also connects up the transformer. If transformers in street boxes are in use he connects up these and their switch gear. Wages for meter fixers are from 7d. to 8½d. per hour.

The transformer fixers merely bring the transformers to the required spot and fix them in their places. Wages about 6d. per hour.

The last class of men in the employ of the Mains Department is that of junction-box cleaners. These men go round all junction-boxes, cleaning out mud and dirt, unstopping ventilation holes, cleaning insulators, painting ironwork, etc. Wages for these men about 6d. per hour.

The third branch of the work of the Mains Department is the removal of faults. In a large undertaking the following arrangement will be found suitable.

At some central point near the main stores about a dozen men are provided with cottages. Half of these men are expected to be at call at night, week and week about. Each house has a bell communicating with the foreman who has charge of fault finding. This may be the foreman of the district in which the stores are situated, or a walking foreman, or even the Mains Engineer. The house of this last is in communication with an exchange at some central point, preferably the Generating Station. To this same exchange are connected the houses of all the district foremen.

If, now, a fault occur in a given district, the district foreman at once telephones to the man in charge of the breakdown gang, telling him the district and, if possible, the exact locality of the fault, and then hurries off to the spot himself.

Meanwhile, the bells in the houses of the men on duty are set ringing, and they at once proceed to the stores and get out the breakdown van, which contains everything necessary for this work.

These men will be skilled labourers of good character, and, in addition to their ordinary pay, live rent free in return for being at call every other week. They are, of course, paid for all time they work when called out.

The above is a brief sketch of the staff of the mains and their duties; the way in which the work is carried out will be described in later chapters (see Chapter XL.).

CHAPTER XXXV.

THE INSTALLATION DEPARTMENT.

THIS department comes more into direct contact with consumers than any other, and the greatest care should be exercised in selecting the staff to ensure as far as possible that each individual shall possess sufficient tact, and be of such good address, as not to offend the susceptibilities of consumers in carrying out the more or less delicate duties involved in the domiciliary visits that have to be made. Above everything, all, and especially the inspectors, must be of the strictest integrity, for, on the one hand, much valuable property in consumers' premises is often exposed; and, on the other, contractors may not be above holding out inducements for the passing of bad work if they find an inspector can be corrupted.

It is desirable to provide each official of this department with some such pass as that shown in Form 20. It is most important that such an authority

FORM 20.—Inspector's Pass.

(Name of Works here.)

No....

Please admit bearer
Mr.....................................
....
to inspect your Electric Light Installation, and oblige,

....
Chief Engineer.

THIS PASS IS AVAILABLE UNTIL
..........................190....

[Size about 4″ by 2¼″.]

should only run for a limited period, say three months, otherwise it may remain in possession of discharged employés, or fall into the hands of dis-

honest persons, who would thus obtain access to consumers' premises on false pretences.

The Installation Inspector should be a man of wide experience in the planning and execution of the wiring of buildings, and, in addition, should have a fair general knowledge of electrical engineering. One who has been in charge of work for a wiring contractor, and has subsequently had some experience of inspection for fire insurance offices, is as suitable as any. His salary should be about £250 per annum.

Under the chief inspector will be a number of assistant inspectors, or in the case of a large area, district inspectors, each being responsible to the chief inspector for a certain portion of the territory covered. These men may be paid from £1, 10s. to £2, 10s. per week each.

A number of youths will be required to help the inspectors by carrying testing instruments, calling to see if alterations required have been carried out, counting lamps, etc.

Lastly, workmen and boys for cleaning apparatus fixed by the Undertakers on consumers' premises will be required.

The first division of the work of this department relates to the examination of consumers' installations to see that they conform to the regulations issued by the Undertakers. The majority of the points involved can be seen at a final inspection made just before the installation is turned on; but it is very desirable that work should be examined during progress, both on account of the facilities so afforded for finding out bad work afterwards covered up, and because much inconvenience and irritation to consumers may be saved by a timely discovery of departure from the rules instead of delay being caused at the last moment.

Much of the work in connection with this department is described later on in Chapter XXXIX., on The Consumer, and is therefore omitted here, as repetition is unnecessary. It is important that in making the insulation test none of the Undertakers' apparatus should be included, otherwise the contractor will have just cause for complaint. This apparatus should be separately tested to make sure it is in order.

If the contractor's work appears to be well done, but the test is low on account of the general dampness of the building, it is quite probable, as already stated in Chapter XXXI. (see p. 378), that the insulation will improve in time, and the installation may be provisionally connected on the condition that it is to be disconnected again if the result is not as anticipated within a reasonable time. A notice suitable for the occasion, together with a form of undertaking to be signed by the consumer, is reproduced in Form 21, p. 406.

In the event of the insulation falling to a dangerous extent, the installation must be cut off, and the consumer should be served with a disconnection notice, a suitable one being shown on p. 407, particulars of the circumstances being noted on the counterfoil.

Great care should be taken to accurately count the lamps and ascertain their candle-power, for it is of great importance to know precisely how the load is distributed on the mains; while if the Hopkinson system of charging be in use without maximum recorders, it is essential to the accurate

FORM 21.—Low Insulation Notice.

(Name of Works here.)

(Address.)

.............................190...

DEAR SIR,

On examining your installation yesterday, our Inspector found that it conformed to our Regulations in all points except that the insulation resistance was below our standard, being megohms instead of megohms.

In view of the fact that it appears probable that this insulation will improve in time, I am prepared to connect it on your signing and returning to me the attached form, and on the understanding that if the insulation resistance does not improve to the requisite extent within a month from this date, the supply will be cut off until the installation conforms strictly to our Regulations.

Yours truly,

....

Chief Engineer.

..................................(Perforated here.)..................................

(Name of Works here.)

From.............................

.............................190...

To the Chief Engineer,

....

DEAR SIR,

I am in receipt of your letter of the.....................

respecting my installation at.....................

and I hereby request you to connect it in accordance with the conditions therein named, and I agree that such connection shall be made entirely at my risk.

Yours truly,

[Size, ordinary business notepaper, flyleaf, blue.]

rendering of the consumer's account. It is often asserted that it is impossible to ascertain the number of lamps with any approach to accuracy, and that consumers frequently alter the power of their lamps; while agreeing that a certain amount of trouble is necessary, and that some changes are

made from time to time, the Author has found the difficulties by no means insuperable; and in his opinion, the extra labour involved, such as it is, is amply compensated for by the advantages attained.

A daily report of the connections, and either a daily or weekly report of the disconnections, should be made to the Chief Engineer, suitable forms for either case being shown in Forms 23 and 24. In order to keep the various books in order, alterations in candle-power of lamps are most conveniently reported by returning the original lamps as disconnected, and those fixed in

FORM 22.—Disconnection Notice.

Counterfoil	(perforated here.)	Notice
No.......		**No.......**
(Initials of Works here.)		(Name of Works here.)
Date.....................*190*...		**NOTICE OF DISCONNECTION.**
Name...............................		................................*190*...
Address...........................		*To*..... ....
....		*Address* ....
		....
		I hereby give you notice that the Insulation of the Electrical Wires and Fittings on your premises having been found to be below the Standard prescribed by the Rules of , and it being dangerous to leave them connected to the mains, I have been compelled to cut them off, and they cannot be reconnected until the defects are made good.
		....
Date reconnected.................		CHIEF ENGINEER.
		NOTE.—The repairs cannot be undertaken by , and you are advised to communicate with the Contractor who fitted up your Installation.

[Size of form and counterfoil 3¾" by 8". Printed on white paper.]

their places as connected. These alterations are ascertained in the course of the periodical inspection of old installations.

In some cases, 'economical' lamps are fixed in place of ordinary ones, and the actual current taken must then be measured. The best plan is to fix a maximum recorder in order to guard against the consumer reverting to ordinary lamps, but if he can be trusted not to do this, the current need only be measured by an ordinary ammeter. A form used for reporting this is shown in Form 25.

Particular attention must be devoted to the balancing of the circuits at the consumers' installations. This is best arranged with the wiring contractor before the job is begun, the requirements being notified when the

FORM 23.—Daily Report of Connections.

(Name of Works here.)

No. 190

DAILY REPORT OF CONNECTIONS.

Works Order No.	NAME	Meter No.	INCANDESCENT					ARC			MOTORS			RATE OF CHARGE
			8 c.p.	16 c.p.	32 c.p.	Various	Equivalent in 16 c.p.	No.	Amp.	Volts	No.	Amp.	Volts	

....*Electric Inspector.*

[Size 7¾" by 8½".]

FORM 24. -Daily Report of Disconnections.

(Name of Works here.)

No. 190

DAILY REPORT OF DISCONNECTIONS.

Consumer's No.	NAME	Meter No.	INCANDESCENT					ARC			MOTORS			RATE OF CHARGE
			8 c.p.	16 c.p.	32 c.p.	Various	Equivalent in 16 c.p.	No.	Amp.	Volts	No.	Amp.	Volts	

..................................*District Electric Inspector.*

[Size 7¾" by 8".]

'label notice' is sent as explained in Chapter XL. It will be found that with a little firmness and tact at the beginning, contractors soon fall into the way of making provision for good balancing, as it involves but little extra trouble on them, and the results are very beneficial to their customers.

Each district inspector must make a full and detailed report each day of all his work, giving particulars of all alterations required. These reports are carefully gone through by the Chief Inspector; and all letters dealing with matters arising out of the reports are dictated by him and passed on to the Chief Engineer for signature.

FORM 25.—Maximum Demand Note.

(Name of Works here.)

No. ....*190*...

VERIFICATION OF MAXIMUM DEMAND,

(FOR FIXED CHARGE PURPOSES.)

To the Chief Engineer,

Please note that the maximum demand was ascertained at M..*of*..

on...................................*190*......, *and found to be as follows, viz.:—*

....

....

....

....

....

Noted.............................. ....

District Electric Inspector.

[Size 4½" by 7¾". Printed on blue paper.]

Closely connected with the inspection branch of the work is the registration of fittings, if this system be adopted. It has already been described in Chapter XXXI., the various forms used being reproduced. It might be thought that the necessary tests should be carried out by the Standardising Department, but it is preferable that the Installation Department staff should effect them, partly because their experience of the behaviour of the fittings in practical operation is useful, and chiefly because it is important that they should be as familiar as possible with the types that are registered in order to prevent mistakes when examining installations.

An account of all fittings submitted for registration is kept in an index book, in which a note is made of their registration or rejection.

The actual fittings themselves are represented each by a sample fixed on boards, those for the same current being grouped together. Each is accompanied by a ticket giving the maker's name and the capacity up to

FORM 26.—Fuse Cleaning Card.

(Name of Works here.) *No.* ______

INSPECTION OF APPARATUS ON CONSUMER'S PREMISES.

Consumer's No. ______ *Date* ______ *190*

Name ______

Address ______

Fuse Box cleaned ______ *Polarity* ______

Fuses found ______ *Renewed* ______ *Size* ______

Meter contacts tightened ______ *Found* ______

Meter starts with ______ *C.P. Lamps*

Meter Label fixed ______ *Caution Label fixed* ______

Insulation of consumer's installation ______ *megohms*

Insulation of Meter from case ______ *megohms*

Insulation of Main side of double pole switch . . } ______ *megohms*

Fuse Box sealed ______ *Meter sealed* ______ *Size* ______ *Amps.*

Meter No. ______ *Maker* ______

LAMPS							MOTORS		
INCANDESCENT					ARC		NO.	VOLTS	AMPS.
8 C.P.	16 C.P.	32 C.P.	50 C.P.	VARIOUS	NO.	CURRENT			

REMARKS ______

______

______

______ *Noted* ______

Fuse Cleaner. *Electric Inspector.*

[Size 5½" by 3½". Printed on thin blue card.]

which the fitting is registered; while a complete list of all registered fittings is issued from time to time.

The Installation Department is also charged with the maintenance of the main fuses, meters, etc., belonging to the Undertakers, which are fixed on

consumers' premises. A number of men known as 'fuse cleaners,' each accompanied by a youth possessed of some technical training, visit the consumers' installations, and the man cleans the apparatus, renewing the main fuses if necessary, and going over all contacts, including those of the meter, to see that they are tight. Meanwhile the youth tests the insulation resistance of the installation, counts and examines the lamps to see if any alterations have been made since the last inspection, tries whether the meter will start with a small load, examines the seals of fuses and meters to see that they are intact, and sees generally that everything is in order. The

FORM 27.—Complaint Note.

(Initials of Works here.)	(perforated here.)	(Name of Works here.)
No..........		*No*.............. ....*19*.....
Date........................*19*......		*Name*..
Name...................................		*Address*..
Address................................		*Complaint*...
Complaint..............................		....
....		....
....		**ELECTRIC INSPECTOR'S REPORT.**
....		*Date*..............................*19*.....
....		....
....		....
....		....
....		....
....		....
....		....
....		....
Complaint Book Folio..................		*Complaint Book Folio*..............................

[Size of form and counterfoil 4⅓″ by 8¼″.]

results of the examination and test are recorded on a card reproduced in Form 26, which is forwarded to the Installation Inspector, who notes the changes in the lamp connections in his daily reports and passes the card on to the Chief Engineer's office, in which the particulars are duly entered up. If transformers are used in consumers' premises, these also are cleaned and examined by the fuse cleaners.

The Installation Inspector has further to investigate complaints as to pressure and the supply generally. When a complaint is received from a consumer, a slip is issued by the Chief Engineer to the Installation Inspector, the form used being shown in Form 27. This gives the nature of the complaint,

FORM 28.—Complaint Book.

181 COMPLAINT BOOK. 181

Date	FROM		Nature of Complaint	Given out to	Report	Date put right
	Name	Address				

[Size of opening $14\frac{3}{4}''$ by $19''$.] This shows the open folio.

and the inspector, after investigation, fills in the result on the lower half. Particulars of the complaint, the report on it and the steps taken to remedy it, if well founded, are entered up in a book shown in Form 28, p. 412, kept in the Chief Engineer's office, and submitted at each meeting to the Board or Committee.

Complaints arise from many causes and can often be traced at once to bad lamps or defective fittings, but if any doubt exists a recording voltmeter should be fixed for a sufficient time.

FORM 29.—Disputed Account Note.

(Initials of Works here.)		(Name of Works here.)
No..........		*No.*......... ....*190...*
Date........................*190...*		*Name*..
Name		*Address*..
Address....................................		*Quarter ending*..................*190...* *Amount of A/c. £......s....d....*
Quarter ending..................*190...*		*Nature of dispute*..
Amount of A/c. *£......s....d...*	(perforated here.)	....
Nature of dispute.......................		....
....		**ELECTRIC INSPECTOR'S REPORT.**
....		*Date*..........................*190...*
....		....
....		....
....		....
....		....
....		....
....		....
Disputed A/cs. folio...........		*Disputed A/cs. folio*........... ....

[Size of form and counterfoil 4¼″ by 8¾″.]

If a consumer dispute his account, a similar slip, shown in Form 29, is issued, and the Installation Inspector calls to see the consumer, questions him as to his consumption, compares it with the registration of the meter, and examines it for any palpable error. If there is reason to doubt the meter, it is removed and returned to the Standardising Department for testing. Particulars of the dispute and of the result are entered in a book, shown in Form 30, p. 414, which is kept in the Chief Works Clerk's office.

FORM 30.—Disputed Account Book.

164 DISPUTED ACCOUNTS. 164

DATE	NAME	ADDRESS	READING OF METER			Rate of Charge	Amount of Account	NATURE OF DISPUTE	Issued to Inspector Folio	Date of Inspector's Report	REMARKS
			Quarter Disputed	Previous Quarter	Con-sumption						

[Size of opening 15″ by 19″. This shows the open folio.]

CHAPTER XXXVI.

THE STANDARDISING DEPARTMENT.

THE Standardising Department is practically self-contained, its relations with other departments being chiefly confined to issuing instruments and receiving samples and objects for test.

The nature of the work of this department has already been described in Chapter XXVI., so that only the staff and organisation call for notice here.

The head of the department should have had a thorough training in the theory of physical and chemical science, and be competent to carry out original research; an engineering education is of secondary importance, though useful as inculcating a due sense of proportion. A suitable man should be obtained for from £250 to £300 per annum.

Under the chief man will be required an assistant at from £2, 10s. to £3 per week, to take charge of the instrument testing, with a number of youths to help in the taking of observations, unpacking and connecting up instruments, etc. A second assistant at about the same salary will be required if there is much chemical testing to be done, but if not, this work can be done by the chief man or by one of the junior assistants under his immediate supervision. The same staff that tests instruments will also conduct tests of transformers, if any be used, and carry out special tests from time to time.

The head of the department will take a direct part in every kind of testing, and lay down the lines on which each branch of the work is to be conducted, his staff merely carrying out the routine work. All records of tests and experiments will be examined, and all certificates and reports will be prepared and signed by him. In the event of original research work being undertaken, he will naturally give particular attention to this and conduct most of the experiments himself.

The question of the taking of pupils, already touched on in Chapter II., may be appropriately referred to again here. A youth who has had a thorough theoretical training at a suitable college is most useful in the Standardising Department, as he is already trained in habits of observation,

is able to read instruments with accuracy, and can intelligently work out results, while he has sufficient knowledge to appreciate the value of costly and carefully calibrated instruments. His services cost nothing; on the contrary, a premium probably has been paid with him. On the other hand, the advantages reaped by the pupil are considerable; he is brought into direct contact with practical work on a large scale; he learns the value of scientific accuracy, and, at the same time, becomes familiar with the exigencies of commercial measurements; he has the opportunity of assisting in tests of the efficiency and behaviour of a wide variety of plant and of new apparatus; while he attains an all-round laboratory experience of great value.

The pupil's work will not, of course, be confined to the Standardising Department, and although this chapter deals only with that department, a short digression may be made to sketch out what the Author considers a suitable course for a pupil articled for two years.

It is assumed that the pupil has had a good education, supplemented by a three years' course at an engineering college, and has attained a certain amount of distinction thereat. He would first spend four months in the Standardising Department, thus keeping up and extending the knowledge he has already acquired. Thence he would pass to the Drawing Office, where he would spend four months; the first portion of the period being devoted to ordinary drawing in connection with extensions or other mechanical work, and the second portion to the surveying and testing work in connection with the mains. Hence it is a natural transition to the Mains Department, in which the pupil would be instructed in the laying of mains, making of joints, etc., this part of his work occupying four months. Having learnt all he could as to mains, he would pass on into the Installation Department and spend two months therein going through the various items of its work, and acquiring a knowledge of house wiring. After this he would enter the Generating Station, spending the remainder of his time, ten months, there, working first as a fireman, then as a greaser, as a driver and, finally, as a switchboard attendant. After this course the pupil would have acquired an excellent general knowledge of the working of a central station, and would be qualified for the post of assistant in a small one or for a junior position in a large one, while during a considerable part of his training he would have been of distinct use to the Undertakers at whose works he had spent his time.

The pupil should be articled to the Chief Engineer personally, as the latter will probably be a member of the principal engineering institutions, and this will facilitate the pupil's entrance into them. A suitable premium is 100 guineas per annum, which should be paid to the Chief Engineer, who should hand over a portion, say 50 per cent., to the heads of the various departments in which the pupil is working, dividing the sum among them accord-

ing to the length of time the pupil is with them. At any one time, there might be two pupils in each department; this would allow for five fresh pupils each year.

To return to the work of the Standardising Department. The bulk of the work done will be in connection with meters. These will be received from the storekeeper, and particulars of their capacity, distinguishing

FORM 31.—Meters Inwards Book.

METERS INWARDS.

Date.	Issue No.	Maker's No.	Size.	Particulars.	Maker.	Remarks.

[Size of page 13″ by 8″.]

number, maker's name, etc., will be entered in the 'Meters Inwards' book reproduced in Form 31. They will then be unpacked, put into working order, and tested for insulation resistance. They will then be connected up on the testing benches, and experiments made to see that they conform to the requirements of the specification.

ORM 32.—**Meters Outwards Book.**

METERS OUTWARDS.

Issue No.	Maker's No.	Size	Maker's Name.	Current	Voltage	Time	Rev⁼		Correct	Actual	Error %		Installed	Reading	Removed	Reading	Name and Address of Consumer
												Insulation Resistance....megs. Starting Current. ....amps. Variation from Mean Heating.. ....hours Passed........ ....190..					
												Insulation Resistance ...megs. ....amps. hours ...190..					
												Insulation Resistance....megs. Starting Current........amps. .hours ...190..					
												Insulation Resistance....megs. ...amps. hours ..190..					
												Insulation Resistance....megs. Starting Current.........amps. Variation from Mean Heating ....hours Passed.................190..					
												Insulation Resistance....megs. Starting Current,........amps. Variation from Mean Heating..............hours Passed.................190..					
												Insulation Resistance....megs. Starting Current. . .....amps. Variation from Mean Heating .... hours Passed . . . .190 .					

Particulars of the tests are entered in the 'Meters Outwards' book reproduced in Form 32, p. 418. At the same time there is affixed to the meter a white card reproduced in Form 33, on one side of which are

FORM 33.—Meters Outwards Card. [Size about 3" by 5".]

Front of Card.

(Initials of Works here.)

METERS—OUTWARDS.

ISSUE No.________ MAKER'S No.________ MAKER________

CAPACITY________ PRESSURE________ READING WHEN ISSUED________

I hereby certify that I have examined and tested this Meter, and find it to be in good order.

____

HEAD OF STANDARDISING DEPARTMENT.

DATE________1 .

This form to be attached to the Meter before it is issued.

Back of Card.

METER FIXED AT.

NAME________________

ADDRESS________________

TOWNSHIP________________

DATE________1 . BY________________

READING WHEN FIXED________ POLES________

This form to be filled in by the Meter Fixer and returned to Head of Standardising Department.

NOTED________________
Head of Standardising Department.

NOTED________________
Installation Inspector.

given particulars of the number, maker, and capacity of the meter and its reading when issued, together with a certificate of the accuracy of the meter signed by the head of the department.

When the meter is fixed at an installation, the meter fixer fills in the name and address of the consumer on the back of the card, the date fixed,

and the reading of the meter when installed, which reading is checked by the one on the front. The card is returned to the Standardising Department after the meter is fixed, and the particulars shown on the back are entered against the test in the 'Meters Outwards' book. When, for any cause,

FORM 34.—Meters Inwards Card. [Size about 3" by 5".]

Front of Card.

(Initials of Works here.)

METERS—INWARDS.

ISSUE NO.__________ MAKER'S NO.__________ CAPACITY__________AMPS

READING__________ CAUSE OF REMOVAL____________________

REMOVED FROM (NAME)____________________

ADDRESS____________________

____

DATE__________190 BY____________________

This form to be affixed to the Meter at the time of removal. The Meter to be returned to Electric Inspector.

Back of Card.

I hereby certify that I have examined and tested this Meter, and find it to be in____________________condition.

(If in bad condition, state defect below.)

____

____

____

____

DATE __________190 ELECTRIC INSPECTOR.

a meter has to be removed, a pink card, reproduced in Form 34, is affixed to it by the meter fixer, the instrument is returned to the Standardising Department and tested, the result of the test being filled in on the back of the card. The particulars of date of removal and the reading are

entered in the columns provided for the purpose in the 'Meters Outwards' book.

If the meter is found to be in good order, it is re-issued, a fresh entry being made in the 'Meters Outwards' book of the new test. If out of order,

FORM 35.—Meter Repairs Card. [Size about 3″ by 5″.]

Front of Card.

METER RETURNED TO WORKS FOR REPAIRS.

FROM.......................... (Name of Works here.)

Issue No..........................*Maker's No*..........................*Make*........................

Size.................*Amps.* *Pressure*....................*Volts.*

(THIS SPACE FOR USE OF (name Works) ONLY, *see over.*)

DEFECT:

CAUSE (if known):

Date.................................... .... *Head of Standardising Department.*

(THIS FORM TO BE AFFIXED TO THE METER BEFORE IT IS RETURNED TO THE MAKERS.)

Back of Card.

(FOR USE OF MAKER OF METER ONLY.)

NATURE OF REPAIRS:

COST TO BE BORNE BY:

Date.........................*190*......

(THIS SIDE TO BE FILLED IN BY MAKERS AND AFFIXED TO METER BEFORE IT IS RETURNED TO THE.............. .... (name of Works here).

a red card, reproduced in Form 35, is attached to the meter, and the instrument is returned to the storekeeper for transmission to the makers. For the guidance of the latter, there is filled in on the front of the card, in addition to the number and size of the meter, the nature of the defect and

the cause, if known. On the back of the card the maker is expected to enter a short account of the repairs effected and a note as to whether the repair will be charged for or not.

When the meter is sent away for repair, particulars are entered in the 'Meters Repairs' book (Form 36), the particulars on the front of the card

FORM 36.—Meters Repairs Book.

METERS REPAIRS

Issue No.	Maker's No.	Sent for Repairs	Returned	DEFECT	CAUSE	Cost borne by	NATURE OF REPAIRS

[Size of opening 12" by 15½".] This shows the open folio.

FORM 37.—Meters Index Book.

Size 8½" by 11".]

being entered at once, and those on the back when the meter is received back from the makers.

An 'Index Book' is supplied to enable a meter to be traced through all three books. A list of consecutive numbers is printed in the first column for the numbers of the meters, and three other columns headed with the name of each book enable the pages in these books on which a meter of a given number appears to be noted (Form 37).

FORM 38.—Daily Report of Meters—Outwards.

(Initials of Works here.)

DAILY REPORT OF METERS.

No. ....

OUTWARDS.

....190

To the Chief Engineer,

Please note that the following Meters were INSTALLED on the above date, and with the undermentioned readings:—

Number		Maker's Name	Size Amp.	Reading	Reading Multd. by	By Whom Fixed.	Where Installed.	
Issue.	Makers'						Name	Address

....

District Electric Inspector.

[Size 6½" by 9".]

A 'Daily Report of Meters Outwards' is furnished by the head of the Standardising Department to the Chief Engineer on the form shown in Form 38, giving full particulars for the use of the departments taking cognisance of the consumer's installation. A similar daily report is made on the form shown in Form 39, p. 424, giving particulars of meters removed.

The system of books described was devised by the Author over ten years ago, and has been found to fulfil very conveniently all practical requirements.

Next in volume to the meter testing is the work of calibrating ammeters, voltmeters, etc. Owing to the relatively small number of these instruments, much less elaboration is necessary. A certificate should be issued with each

FORM 39.—Daily Report of Meters—Inwards.

(Initials of Works here.)

No. .... DAILY REPORT OF METERS.

INWARDS.

.... 190

To the Chief Engineer,

Please note that the following Meters were REMOVED on the above date for the reasons stated below.

NUMBER.		MAKER	SIZE AMP.	READING	WHY REMOVED	READINGS MULTIPLIED BY	WHENCE REMOVED	
ISSUE	MAKERS						NAME	ADDRESS

....

Electric Inspector.

[Size 6¼" by 8".]

instrument, and a detailed account of the tests made be kept in a suitable book, separate books being devoted to ammeters, voltmeters, and miscellaneous instruments.

The Standardising Department is the depository for all standard measuring instruments of the undertaking, and the Chief of it should be held responsible for their safe keeping. Inasmuch as officials of other departments may from time to time require the loan of certain apparatus, a proper

record of all apparatus so lent should be kept in the 'Instrument' book reproduced in Form 40.

Particulars of chemical tests will be entered in books that can readily be devised for the work dealt with, while the record of original research will naturally take the form of a special account or diary.

FORM 40.—Instrument Book.

INSTRUMENT BOOK.

DATE	INSTRUMENT REQUIRED	ISSUED TO	TIME		Returned in good order to
			Taken out	Returned	

[Size of page $12\frac{1}{2}''$ by $7\frac{1}{2}''$.]

The examination of stores will be recorded in the general book of tests, and certificates will be issued to state that the samples are of the guaranteed quality.

All certificates issued, other than those relating to meters, which are specially dealt with, should be made out on printed forms torn from books arranged with carbon-paper so that an exact duplicate can be preserved.

CHAPTER XXXVII.

THE DRAWING OFFICE, THE TRANSFORMING STATIONS, AND STREET LIGHTING.

THE three subjects in this chapter are grouped together, not because they are closely related, but because the description of the work of each need only be short, and is not, therefore, sufficient by itself to form a separate chapter.

Drawing Office.—The chief draughtsman should be a man of varied experience and one accustomed to maintaining discipline. A suitable salary for the post is £250 per annum. The men under him comprise mechanical draughtsmen, surveyors, electricians, and clerks.

The mechanical draughtsmen are of three kinds, viz.: (1) Those used to the ordinary work of a mechanical engineer's drawing office, and competent to plan out machinery and plant and make designs for new work; (2) architectural draughtsmen, capable of designing the buildings for extensions, sub-stations, etc.; and (3) draughtsmen having a good knowledge of mechanical work supplemented by a fair electrical knowledge, their work being to draw out switchboards, fittings for use in connection with the mains, etc.

It is practically impossible to get one man who can efficiently combine the duties of (1) and (2), but those of (1) and (3) may occasionally be merged in one individual. The first two will only be required while the undertaking is growing at a rapid rate and can probably be dispensed with ultimately, but a draughtsman of some kind will always be wanted, and the third will probably be able to acquire sufficient knowledge of the work of the other two to enable him to do all that is required, and he is likely to be the most generally useful. A suitable salary for these draughtsmen is from £2 to £4 per week.

The surveyors employed do not require any very extensive knowledge of surveying, practically all that is necessary being the ability to use a dumpy level and a knowledge of a field book and the plotting of their observations. They are chiefly engaged on recording the laying of the mains, a matter

fully described in Chapter XXIV. In addition to this they will survey and stake out any new land that may be purchased.

The electricians are charged with the testing of the mains after laying, and the amount of training necessary for this is not very extensive. A salary of from £1, 10s. to £2 per week is sufficient for the principal tester, and from 15s. to 25s. per week for his assistant. In addition to this testing, the principal man will act as inspector at the maker's factory to see that the requirements of the Chief Engineer's specifications are carried out.

The clerks are required for making out the balancing sheets relating to consumers, described in Chapter XXIV.

There is not much to describe in connection with the drawing office, on account of the bulk of the work having been given in detail in other chapters. It may be pointed out that care should be taken to properly index all drawings, so that any one wanted may be found at once.

It is convenient to keep all drawings in pencil; it is mere waste of time to ink them in, and if they are in pencil, alterations can readily be made at any time. A standard tracing in ink should be made of each drawing when completed, and should never be allowed to leave the drawing office. Copies may be traced or prints taken from it when required.

The best prints are undoubtedly those in black lines on a white ground, since they can be coloured, and are in all respects as good as drawings. The process is very simple, but the paper is somewhat expensive. Blue prints cost about half, and answer well enough for many purposes.

In connection with this subject may be mentioned an apparatus for printing that is invaluable in a busy office. It consists of a glass cylinder half the circumference of which will take the largest tracing it is desired to print from. The cylinder is placed vertically, and the tracing wrapped round it, two being printed at once, one on each half circumference. Next to the tracing is placed the sensitised paper, and outside this a sheet of canvas, secured tightly by means of straps. An enclosed arc lamp, burning with a long arc on 200 volts, gives a strongly actinic light, and is gradually lowered from the top of the cylinder to the bottom, its motion being controlled by a 'scapement and pendulum. The bob on the pendulum is adjusted until the rate is such that the lamp effects the printing on passing once downwards. The apparatus gives most excellent and certain results, and the time taken is very short, less than ten minutes for a double elephant print.

It is prudent to keep all standard tracings and drawings and the records of the mains in a fireproof chamber, for their loss would be irreparable.

Transforming Stations.—These should be placed in the charge of one engineer, who is responsible for their maintenance in proper running order. The nature of the plant in the sub-stations varies with the system employed, but in all it is chiefly electrical, the mechanical part in no case being more

than a revolving armature. For this reason, the engineer should be an electrical one, and any mechanical repairs required can be effected by the mechanical engineer's staff from the generating station. A suitable salary is from £150 to £250 per annum, or more in a large system.

The transforming stations suffer from the disadvantage that they are scattered, and it is therefore difficult to keep an efficient watch over the men employed in them. For this reason, it is particularly important that the men engaged in them should be steady and reliable. Experience shows that time-expired naval men, especially torpedo men, are exceedingly satisfactory to place in charge: they are steady, self-reliant, prepared for emergencies and well disciplined. Each sub-station will require at least two, and some three; one of these may live at or near the sub-station so as to be at call if wanted. If no living accommodation is given, the wages may be from £1, 10s. to £2 per week. A boy should be in attendance with each man, so that in case of accident an alarm may be given.

The transforming stations just referred to are large overground ones of many hundred, or several thousand, kilowatts capacity. For small sub-stations, usually placed underground, a staff will be required to go round from time to time to see that all is in order.

Except in the case of small sub-stations, every transforming station should be in direct telephonic communication with the generating station, so that no time may be lost in case of emergency; this will also give the engineer the opportunity of surprise calls, so that he may ascertain that his men are on the alert.

A log of the plant in use and of the output should be kept for each sub-station, and a weekly report be presented by the engineer in charge to the Chief Engineer.

Street Lighting.—This department is of great importance, because the light is more in evidence in the streets than anywhere else, and any interruption or unsteadiness is an exceedingly bad advertisement for the Undertakers. Assuming that good lamps have been selected and a steady pressure is given, success is principally dependent on careful attention to detail, for neglect or slovenliness will cause the best of lamps to burn badly.

The inspector in charge of this department should have a thorough knowledge of the mechanism of the lamps, and should give his close personal attention to the work of his staff. A suitable salary is from £150 to £200 per annum.

The staff consists of three divisions, viz.:—(1) Trimmers, (2) Repairers, (3) Testers.

The trimming staff will vary in number with the amount of lighting done. If the lighting be general, each trimmer should be able to trim, and keep in thorough order, 50 lamps per day. Each trimmer should have a boy to help him and to look after the ladder while he is at the top of the

post. The trimmers' wages are from 6d. to 7½d. per hour; and men should be chosen who are used to climbing and are not likely to turn giddy; naval men are well suited to the work.

It is practically essential to have a small repairing staff, as the wear and tear on arc lamps is considerable, and it is always necessary to get repairs done quickly. A few lathes are practically all the tools required, and one or two men can get through as much work as is likely to be wanted.

All lamps, whether new or repaired, should be thoroughly tested before being fixed on the circuit, and be carefully adjusted to take the right amount of current. It is useful, if there is a great deal of street lighting, to provide a photometer room.

CHAPTER XXXVIII.

THE CLERICAL DEPARTMENT.

THE clerical work in connection with a large undertaking is very heavy and calls for good organisation. As far as possible the engineering staff should be relieved of clerical work, for not only is it wasteful for a highly-paid official to occupy his time with work that a youth at £1 per week could do, but, as in all labour, the man whose profession it is will do the work far better and more quickly than one to whom it is a merely incidental part of his duty.

This work, as has been shown in the general scheme, is divided between three departments, viz.: those of the (1) Chief Works Clerk, (2) Private Secretary, and (3) Secretary.

The chief works clerk has to look after everything in connection with the ordering and issuing of stores as required; the checking of the accounts for goods purchased; the keeping of the time worked by the men, and the preparation of the account of the wages due to them each week. From the returns of stores and wages, he has to work out the cost of each Works Order, whether in connection with the generating station or the mains, and, from the various reports supplied to the Chief Engineer, to ascertain the cost of production. He has charge of the whole of the clerical work in connection with the receipt of applications from consumers, and the issue of Works Orders for their connection to the mains; he enters up the particulars of the consuming devices actually installed, and of any changes or additions that may be made from time to time; he looks after the readings of the consumers' meters; and he supplies the particulars of their consumption of energy so that the secretary can charge their accounts. All the reports from the various engineering departments pass through his hands, and he prepares digests and summaries of them under the direction of the Chief Engineer. The salary for this responsible post should be from £300 to £500 per annum, according to the magnitude of the undertaking.

The working of this department will now be described as far as possible, but for certain portions of the work the reader is referred to special chapters on The Consumer and The Mains.

So far as regards the storekeeping, one main stores should be provided in a central position, and there should be accommodation for the principal storekeeper to live on the spot, so as to be accessible at all times, thus obviating the difficulty of division of responsibility.

As far as possible, all stores should pass through the main stores, but if these be not at the generating station, a separate store for materials used in the engine room will be necessary, or if there be more than one station, a store for each, and each one will require a storekeeper who should be subordinate to the head storekeeper.

In a large district it will also probably be found convenient to have a number of small subsidiary stores for the materials used in making the service connections. The goods would be issued in bulk to such stores, and the whole quantity kept so small as to obviate the necessity for a special storekeeper, the district foreman looking after and being held responsible for them, giving account at frequent intervals.

It is frequently desirable, in order to avoid unnecessary expense for carting, to deliver bulky materials such as bricks, crushed stone, sand, etc., directly on the work so that they never pass through the stores. A careful account of these must be kept, and the head storekeeper be advised of the particulars each day.

Yearly contracts will be made through the Secretary's department for all ordinary goods, and quotations obtained for those of a special nature. As the stores are required, definite quantities are ordered day by day. The Author has found the following arrangement convenient.

A 'Requisition Book,' of which a facsmile is reproduced in Form 41, p. 432, is provided. In this are entered the quantity and description of the goods required, together with the name of the firm from whom they are to be ordered if a contract for their supply is in force; if not, the space for this is left blank. Each item is initialed by the head of the Department requiring the articles, or, for ordinary goods, by the storekeeper, who has instructions to keep his stock from falling below a certain point.

This book is submitted to the Chief Engineer each day for his approval After the items have been initialed by him to signify his assent, and the firms indicated from whom goods not covered by contract are to be obtained, the orders are made out by the accounts clerk on a form reproduced in Form 42, p. 433. This gives particulars of the goods required and the destination to which they are to be forwarded. Each order has a distinguishing number, and the contractors are required to quote this number on their accounts, failing which they will not be passed for payment. The order form is on thin paper, and a record is kept on the counterfoil by means of carbon paper. On this counterfoil a space is provided headed 'Analysis,' and in this is written the name of the account to which the cost of the goods is to be charged. By this means accuracy in allocating the expense is ensured, since

the 'Requisition Book' is at hand at the time to show by whom and for what purpose the goods are required.

All goods supplied have to be accompanied by a delivery note stating

FORM 41.—Requisition Book.

REQUISITION BOOK.

Date	STORES REQUIRED	TO BE ORDERED FROM	REQUIRED FOR	Department	Approved

[Size of page 15" by 9½".]

from whom they come and giving particulars of them. When the materials arrive, they are received, examined, counted and weighed by the store-keeper, and all particulars entered up by him in the 'Stores Received' book

FORM 42.—Order Book.

Analysis......................................*Account Passed*..................1......

No..........

....1......

M.......... ....

....*Chief Engineer.*

(perforated here.)....

(Name of Works here.)

No..........

..........................1......

M...

Please deliver at the STORES

at... **(CARRIAGE PAID).**

....*Chief Engineer.*

an order for the same, duly signed, be produced if
on the day following the delivery of the Goods, and
If there is more than one delivery of Goods during
must be rendered not later than the of the

by a Delivery Note, showing their
of firm supplying them. Hours: 6-0
. to 12 noon.

The right hand form is the order, the left the counterfoil. [Size of each, about $6\frac{1}{2}''$ by $7\frac{1}{4}''$.]

FORM 43.—Stores Received Book.

STORES									RECEIVED.		
Date	RECEIVED FROM	QUANTITY	PARTICULARS		WEIGHT	Ledger folio	Price	AMOUNT	AMOUNT	Folio	STOCK ANALYSIS

[Size of opening 15½" by 20".] This shows the open folio.

reproduced in Form 43. These particulars are independently obtained by him and compared with the delivery note and the Requisition Book, any discrepancy being at once notified to the Accounts Clerk. The Storekeeper

FORM 44.—Ganger's Daily Return.

(Initials of Works here.)

.................................190......

MAINS DEPARTMENT.

Daily Return of Material Received on Works Direct from Contractors.

From whom Received.	Quantity.	PARTICULARS.	Received for W. O. No.

Note.—This Return to be Sent to the Chief Engineer with the Contractor's Delivery Notes and the Foreman's Order Tickets for the Material.

Order Tickets Checked by..

Entered Received Book, Folio..............

[Size 13½" by 8½".]

must on no account enter the goods from the delivery notes, as in such a case there would be no check on the contractors. On the receipt of goods, the Storekeeper notifies the official who requisitioned them of their arrival.

When goods are delivered directly on the work without going through

the stores, a return is made up by each ganger of the goods so received by him; these returns are collected daily by a walking foreman, who makes up a daily account on the Form shown in Form 44, and hands it in to the Storekeeper, who enters the particulars in his ordinary books in the same manner as if he had received the goods into the Stores.

In certain cases goods received are defective or not up to the contract quality, and are returned to the Contractor supplying them. Particulars of these are entered in red ink in the ordinary 'Stores Received' book (Form 43), and are then debited to the contractor. Empties returned to the senders are similarly dealt with.

The Storekeeper's book is handed to the Accounts Clerk from time to time, and the stores received are entered up in the 'Personal Ledger.' In this a separate folio is devoted to each contractor, and particulars of the goods received are shown on the Cr. side, while on the Dr. side are entered

FORM 45.—Stamp for Accounts.

Goods Recd.............................

Price............Checked..............

Amount not Checked

Account Examined....................

Certified for Payment Subject to Price and Amount being correct.

....

[Nat. Size.]

the amounts of the accounts passed for payment from time to time. The goods received are next entered in the 'Impersonal Ledger,' in which a distinct folio is assigned to each heading of the Analysis, the goods received being entered on the Debtor side, and the goods issued for use on the Credit side. The folio headings in this book agree with the analysis of accounts described in Chapter XXIX. These ledgers do not need reproduction.

When the account for the goods is received from the firm supplying them, the quantities are compared with the Personal Ledger and the stamp reproduced in Form 45 is initialed by the Accounts Clerk opposite 'Goods Recd.,' and the account to which the goods are to be analysed is stamped or written on the account, the word 'Contract' or 'Quotation' being also stamped on it to show whether the goods it relates to have been ordered under the ordinary yearly contracts or whether a special quotation was obtained for them. It is then passed to the Chief Works Clerk, who examines it and the analysis of the cost, and, if correct, initials it opposite 'Examined.' It is then submitted to the Chief Engineer, who certifies it for payment subject to the price and arithmetic being found correct, attaching his initials in the space provided. It then goes forward to the Secretary's office, where these items are checked, and it is then paid by the Accountant.

When the goods supplied form the subject of a special contract, such, for instance, as the delivery and erection of plant or the construction of buildings, the amount and value of material delivered will be reported by the Clerk of the Works or other person watching the work, and no cognisance will be taken of the matter by the Storekeeper. The payments will then be

FORM 46.—Certificate Book.

(Name of Works here.)

CERTIFICATE OF PAYMENT.

No.........

In respect of work executed for the...

Contractor...

Address...

Nature of Contract...

Carried out at...

Amount of Contract (including £..........for extras) £..................

	£	s.	d.	£	s.	d.
Value of Contract work executed.........						
Value of additional work, as per account herewith.........						
Less instalments previously paid (See Certificate No..........)...						
Deduct Retention under Contract........per cent. on £...............						
Balance due to date, which amount is hereby certified for payment.........						

Folio in Contract Book.....................

Signature.....................................

Date...

Chief Engineer.

[Size 6½" by 8".]

made by certificate, a convenient form being reproduced in Form 46. This shows the amount of the whole contract, particulars of the sum allowed for extras, which will be deducted if no extras are ordered, the value of the work done or materials delivered, the amount certified for payment and the amount of money retained under the contract, if there be a maintenance clause with retention of money.

If extra work be required to be done under the contract a special order form should be employed. A suitable one is shown in Form 47.

So far we have traced the goods into the Stores, and the mode of certifying payment for them. We have now to consider their issue from the Stores to the various departments.

No goods are issued to any person unless he produce a written order, signed by his foreman, stating the quantity and nature of the materials wanted, and the Works Order number of the job for which they are required.

FORM 47.—Order for Extra Work.

[Name of Works here.]

Contract No. ....

For..

With Messrs..

ORDER FOR EXTRA WORK. *No.*...........

To the Contractor,

Please carry out the following Work, the same to be paid for by [name of Co. or Corporation here] *as an extra out of the sum reserved for the purpose in your Contract.*

[NATURE OF WORK]..

....

....

....

....

Chief Engineer.

The above Order No. must be stated on all statements and accounts for this extra.

[Size $6\frac{1}{2}''$ by $7''$.]

A suitable order form is shown in Form 48; and the workman receiving the articles is required to sign for them on the order in the space provided.

It may happen that the goods ordered are not in stock, or for some other reason the order is not executed exactly as it stands. In order, therefore, to provide for this contingency and ensure the foreman checking the quantity of goods booked out to the work he is responsible for, the Storekeeper is required to make out a Delivery note, shown in Form 49, giving particulars of the material actually issued to the bearer of the order. This note is handed to the foreman with the goods, and when he has checked them with it, is signed by him and sent on to the Mains Engineer, who satisfies himself that the material in question was properly required for the work, and initials it, passing it on to the Accounts Clerk.

Full particulars of the transaction are entered by the Storekeeper in the

FORM 48.—Foreman's Order Form.

[Initials of Works.]

No........

MAINS, ETC.

W. O. No.......

..................*190*...

Issued to

....

[perforated here.]

W. O. No.............

No........

[Initials of Works here.]

MAINS, ETC., DEPARTMENT.

..................................*190*

To the STOREKEEPER,............................

Please deliver to bearer..

(*Signed*) ....

(*Received*) ....

[Size 4½" by 7".]

FORM 49.—Storekeeper's Delivery Note.

(Initials of Works here.)

No............ ....*190*...

To Foreman...................................... W. O. No...............

The following material has this day been issued for use on the above Works Order:—

....

Storekeeper.

Material as above received in good order on..................*190*... *by*

....

Foreman.

This Delivery Note must be signed by the Foreman in charge after the material has been checked, and forwarded to the Mains Engineer.

Correct in Issued Book fol.....................

[Size 4½" by 7".]

(Name of Co. or Corpora

Date	Quantity	Description	Weight				Issued from	Price	Gross Amount	Discount	
			Tons	c.	q.	lbs.				Rate	Amount

[Size of opening, 19½" by 30".] This shows the open folio.

'Stores Issued' Book reproduced in Form 50. This, also, is handed to the Accounts Clerk, and the quantities issued compared with the delivery notes and entered on the Cr. side of the Impersonal Ledger.

It is impossible in all cases to exactly gauge the amount of material

FORM 51.—Transfer Sheet.

(Initials of Works here.)

——— ....190...

MAINS DEPARTMENT.

RETURN SHOWING MATERIAL TRANSFERRED.

Quantity	DESCRIPTION	From W. O. No.	To W. O. No.	To STORES.

Entered in Issued book by................................Fol..........

[Size 13" by 8".]

required for a given Works Order. If convenient, the surplus goods are returned to the Stores and a credit note for them sent to the foreman. Particulars of the goods returned are then entered in the Stores Issued Book in red ink and the Works Order credited with them.

When the materials are bulky, or the work is situated some considerable

distance away, useless expense would be involved by returning the goods to the Stores, and they are therefore used for carrying out some other Works Order in the neighbourhood; and in order to keep an accurate account of the cost of each job, a transfer sheet must be employed, such as that shown in Form 51, to keep account of the materials handed over. This sheet is then

FORM 52.—Tool Book.

Tools Issued to..

Date issued	Number of Tool	Nature of Tool	Date Returned	Why Returned

[Size of page 13″ by 8″.]

handed to the Storekeeper, and the one Works Order credited and the other debited in the Stores Issued Book with the goods transferred.

It is impracticable to carry out this system for minute quantities of stores, such as jointing materials and small sundries, for a given quantity of these may be divided among a dozen different jobs. These are, therefore, booked out to a general Works Order, and at the end of the year the whole

amount is apportioned as fairly as possible between the various Works Orders.

From the Stores Issued Book, the cost of the materials used on each Works Order is accurately determined, and the cost of labour from the Wages Book; there remain, however, a number of items of cost to be added.

FORM 53.—Stores Loan Book.

STORES LOAN BOOK.

Date	Quantity	Size	Particulars	Issued to	Date returned in good condition

[Size of page, 13″ by 7¾″.]

Among these may be mentioned the draining of junction boxes, the removal of gas and water services, the reinstatement of paving and flagging, carting and tipping of spoil, etc. An account of these is kept in a Sundries Journal, and the cost posted directly to the various Works Orders.

The whole cost is finally arrived at by adding to each Works Order its due proportion of the costs of management, sundry jointing materials, and wear and tear of tools.

The procedure just described applies equally to Works Orders for mains, services, and engine-room stores. In order to keep the matter in proper form, a general Works Order is issued each year to cover the cost of generating current, and all stores not covered by other orders are booked to this general Works Order.

A special case applying to a particular class of stores may be mentioned, namely, that of meters and electrical instruments. These are received by the Storekeeper and taken out of the packing cases by him. They are then sent on to the Standardising Department, and each instrument is carefully opened, tested, adjusted if necessary, and returned in working order, ready for use, to the Storekeeper. This involves the instrument being booked out of the stores and in again, and also an account being kept by the Standardising Department, as explained in Chapter XXXVI.

The procedure with regard to the issue of tools may here be explained. Each tool is numbered, and when issued to a workman a note is made in a book provided for the purpose reproduced in Form 52. In this book a folio is devoted to each man and a list made of the tools issued to him and their numbers. From time to time an inspection is made of each man's kit and an explanation required if any tools are missing, or if he have any that have been issued to other men.

Occasionally goods are borrowed from the Stores for temporary use and subsequently returned. A proper account should be kept of these, or confusion is certain to result. A suitable book for this is shown in Form 53.

The Stock Accounts so far described have related in all cases to the cash value of the goods, but it is important that the Storekeeper should at all times know the exact quantity of any particular article that he has in stock. In order to secure this, rough books, shown in Form 54, are provided, in which he enters the number of articles or weight of material received and issued, and each week he balances up these books, bringing forward his stock in hand. Cables forming a very important item of the stock, separate books shown in Form 55 are convenient.

Stock is taken with great care annually, and somewhat less completely each quarter. All stores in stock on a given date are entered in the Stock Book and the estimated value placed against each item, an appropriate amount of depreciation being allowed.

The value of the stock standing under the various headings is credited to the corresponding stock accounts in the Impersonal Ledger, and any discrepancy or loss is written off annually. The ordinary Stock Book is shown in Form 56.

Suitable wages for the head Storekeeper, who should have received a thorough training in the class of work, and who, it need hardly be said, should be a man of the strictest integrity, are from £100 to £150 per annum, a cottage, fuel, and light being given in addition. The assistant

Storekeepers may be paid from £1, 5s. per week, rising to £2 per week, according to length of service.

The next important branch of the work of the Chief Works Clerk is the checking of the time worked by the men.

The system of time sheets has already been explained in Chapter XXXII.

FORM 54.—Rough Stock Book.

Dr.		.... *Size.*	*Received from*............				Cr.
Date	Folio	Quantity	Weight	Date	Folio	Quantity.	Weight

[Size of page, 15¾″ by 10″.]

Each man is identified by a number, and is supplied with a brass token bearing the number and some impression to prevent the substitution of unauthorised tokens.

These tokens are known as 'time checks,' and are hung on a board in the time lodge through which the men pass when entering upon and leaving

their work. When going home each workman is handed his check by the timekeeper, and on arrival next morning drops it into a slot provided for the purpose.

At a given time a shutter is slid, blocking this slot, and men arriving after the prescribed time put their checks in another slot; after a given interval this slot is blocked and a third is opened. The interval between the first and second shutter being slid is usually half an hour, and between the second and third two hours, the men whose checks are placed in the second and third slots being half an hour and 2½ hours late respectively.

FORM 55.—Cable Stock Book.

CABLE, ETC., STOCK BOOK.

Name .... *Size of Cable* .... *Weight per mile* .... *Price per mile* ....

Date	Stock in hand Mls. Yds.	RECEIVED			ISSUED						
		Length Mls. Yds.	Net Weight	Particulars	Date	Works Order No.	Length Mls. Yds.	Fort-night ending	Length Mls. Yds.	Total Length Mls. Yds.	REMARKS

[Size of opening, 15" by 19½".] This shows the open folio.

The checks drop into a box divided into three partitions, labelled according to the time of arrival. They are removed by the Timekeeper and each workman's time noted, this being afterwards compared with that shown on the time sheet handed in by the workman after being duly checked and initialed by his foreman.

When the men are working away from the station, as, for instance, on mainlaying, a similar box to that in the time lodge is taken to the place where operations are going on. The shutters are worked by the foreman in charge of the job, and are so arranged that they cannot be tampered with. The box is securely locked and is sent back to the head Timekeeper each day.

The time worked by each man day by day is entered in a book reproduced in Form 57, the overtime rates being allowed for and entered as the equivalent number of hours of ordinary time in red ink, the different colour indicating that overtime has been worked. At the end of the week, the time worked by each man is added up and the total entered in this book, which is then handed to the Works Wages Clerk who has charge of the Wages Book described in a previous chapter (see p. 350). In this book are entered the names of the men, their numbers, classification, and rate of pay, and against each name is set the total number of hours shown

FORM 56.—Ordinary Stock Book.

Dr.									Cr.
Date					Date				
	To Goods Received					By Goods Issued			

[Size of opening, 20″ by 31″.] This shows the open folio.

by the time book. The wages due to each man are then worked out and entered. If any deduction is made for a thrift fund, the amount is calculated on the wages due and put down in the column provided.

The time sheets are checked by the engineer under whom the men work, or by their foreman, to see that their time is assigned to the proper Works Orders, and when this has been done, they are passed on to the Works Costs Clerk, who enters the time on Weekly Cost Sheets, shown in Form 58, p. 449. From these sheets the cost of labour expended on each Works Order is ascertained and charged to the various Works Orders.

From the Weekly Cost Sheets the analysis of each man's wages is made up, the various items being entered in the columns provided in the Wages Book and corresponding with the Board of Trade classification, as previously explained.

This system provides a complete check on the Wages Book, and renders it practically impossible that an error should go undetected; at the same

FORM 57.—Time Book.

(Name of Works here.)

Week ending Wednesday ______ ______ *190*__

No.	NAME	DESCRIPTION	WEDNESDAY.	THURSDAY,			FRIDAY,			SATURDAY,			SUNDAY,			MONDAY,			TUESDAY,			WEDNESDAY.	GRAND TOTAL
			OVERTIME	ORDINARY	OVERTIME	TOTAL	ORDINARY	OVERTIME	TOTAL	ORDINARY	OVERTIME	TOTAL	ORDINARY	OVERTIME	TOTAL	ORDINARY	OVERTIME	TOTAL	ORDINARY	OVERTIME	TOTAL	ORDINARY	HOURS

Examined.. ....

Chief Engineer. *Timekeeper.*

[Size of opening, 13" by 15½".] This shows the open folio.

time, it has the advantage of enabling the cost of any work to be ascertained with great accuracy.

The rates of pay having been checked by the Chief Works Clerk, and the various additions having been checked to see that the totals balance, the book is initialed by him and submitted to the Chief Engineer, who initials it and sanctions payment being made.

If any advances of wages or special allowances are to be made, particulars of the amount recommended, together with the date and amount of the last increase, are entered in a special book, which is submitted to the Chief

FORM 58.—Weekly Time Costs.

(Name of Works here.)

WEEKLY TIME COSTS. *Week ending*..............................1......

Name..*No*............

W.O. No.	Wed.	Thur.	Fri.	Sat.	Sun.	Mon.	Tues.	Wed.	Total for Week.	Rate.	Amount.	Folio W.O. Book.	Analysis.	Folio.
TOTALS .														

[Size 8¾" by 11½".]

Engineer for his approval before the Wages Book is made up, the new rate, if sanctioned, being then entered.

The Wages Book is passed on to the Secretary's Department for payment to be made by the Pay Clerk there. A cheque for the amount is drawn by the Cashier, and the cash brought by the Pay Clerk, who himself pays it to the men.

The money is counted out, and the exact amount, with a note of the sum, is placed in a circular tin box stamped with the workman's number. Each man is provided with a pay check resembling his time check, but differing from it; this he hands in to the Pay Clerk, and receives in exchange for it the tin box containing his wages.

The time kept by officials is checked by requiring them to sign when they arrive and when they depart in a book kept in the time lodge. For those officials whose duty takes them out at intervals during the day, another book is provided in which they sign as they go out, giving the time and their destination. On their return, they fill in the hour they come back. Both these books are submitted each day to the Chief Engineer.

The minor officials are paid through the Wages Book, but without using time sheets or checks. The principal ones are paid monthly by cheque direct from the Cashier.

The head Timekeeper should be paid from 35s. to 45s. per week, and should be chosen for his integrity and resoluteness of character; he should be a man who will be proof against threats and cajolery on the part of the men, for his position is not an enviable one at the minute when the men are due and he has to alter the shutters in the check box!

Assistant timekeepers may be paid from 18s. to 30s. per week, according to length of service.

The Pay Clerk who handles the cash for the wages should be guaranteed by sureties for an amount equal to at least the average amount of the wages bill, and should be paid a fair salary. The Works Wages Clerk should be paid ordinary clerk's wages.

The work relating to consumers next claims attention. The greater part of this is described in Chapter XXXIX. on The Consumer, and need not, therefore, be further enlarged on here. We may, therefore, at once pass on to the portion not referred to there, namely, the reading of the meters. For this a staff of meter readers will be required, the number depending upon the magnitude of the undertaking and the compactness of the area. In the central parts of a town in which the supply has been well taken up, each man can read about 130 meters per day, but in a scattered district, in which the individual consumers are some distance apart, 80 meters per day would be a good average. Meter readers usually begin as youths at about 18s. per week, rising yearly by increments of two shillings to, say, 36s. per week. They should be chosen for their intelligence and general respectability, an irreproachable character for honesty being essential, on account of their having to enter consumers' premises in which property of value may be exposed to them, and they should have good health, as they are out in all weathers and have a good deal of walking.

Meters must be read at least once a quarter, but several check observations should be taken between these readings in order to discover faulty meters, say once a month. If this be done, the intermediate readings will often enable an account to be rendered on a fair and satisfactory basis, even though the meter stop or race during a part of the quarter.

The readings are entered in a book which shows the name of the consumer and the number of the meter, and has a number of blank columns

for the readings. One is provided for each district, the consumers being arranged in such order as is most convenient for the meter reader to visit the premises.

These books are submitted periodically to the Chief Works Clerk, and, after he has examined them, are passed on to the Secretary's Department, in which the accounts are made out by the Accounts Clerk and rendered to the consumers, the money being collected by the Cashier and his staff and paid into the bank.

The last branch of the Chief Works Clerk's duties relates to the reports presented by the various officials to the Chief Engineer. After the latter has examined them, they are passed on to the Chief Works Clerk, who abstracts the information from them and compiles weekly, quarterly, or yearly returns as required.

Private Secretary.—We now pass on to the department of the Private Secretary, which is a comparatively small but important one. This official should possess a thorough knowledge of shorthand, typewriting, and general office work. An appropriate salary is about £200 per annum. Under him will be a sufficient number of expert shorthand writers and typists. These should all be able to write at the rate of not less than 150 words per minute, and be able to read one another's shorthand. Every shorthand writer should also be a typist, so that he may write his own transcript, as speed and accuracy will be thereby promoted, but one or two typists who are not shorthand writers can be employed for copying documents.

A clerk used to proof reading will be found of great use, as it is important that letters and reports should be carefully read through to avoid clerical errors; a man used to printing-office work develops an instinct for noticing mistakes.

The duties of the Private Secretary consist in having letters and reports, etc., ready for the Chief Engineer, and, if the correspondence be heavy, in opening and sorting the letters for him. He will be responsible for the safe keeping and proper filing away of all correspondence, the American system in which the letters received are filed away in drawers with the copies of the replies to them, being the arrangement best suited to modern requirements, and greatly to be preferred to the guard book and press copy book of the period antecedent to the typewriting machine, both on the score of convenience and very great economy of time.

It is strongly advocated that all correspondence should pass through the Chief Engineer's hands, and that no departure should on any account be allowed from this rule. In this way the Chief is kept in touch with everything that is going on, and no official has the chance of marring his general policy.

Many of the letters received will, of course, have to be sent to the heads of the various departments for attention, and, if desired, these officials may

be allowed to draft a reply for the Chief to sign or they may simply send him the information to enable him to answer the communication himself. When the actual letter is sent out of the office, it is important that a record of its whereabouts should be kept. For this purpose, the Author has found the slip shown in Form 59 very useful. This is numbered, and the name of the official written in with instructions as to what he is required to do with the letter; the slip is gummed so that it may be attached to the letter. On the counterfoil is noted the date the letter is sent, the name of the correspondent, the number of the slip, and the name of the official deputed to deal with it, while a blank is left for the date he returns it. By glancing at the counterfoils it is easy to see at once whether any letters are left outstanding, and who has them, and only a few seconds are required to fill in the slips.

FORM 59.—Slip for Letters.

	(perforated here.)	
Date .... *No.*		*No.* ....
Letter from		*To* ....
.... *Dated*		
Sent to		
Date Returned		

[Size of slip and counterfoil, 2″ by 6″.] It is convenient to have 3 or 4 of these on the page, perforated between, so as to tear out easily—the slips being, of course, consecutive.

A careful record of the stamps used, and of the posting of letters, should be kept to prevent fraud and disputes as to the dispatch of letters.

The Private Secretary will see that all the reports are ready for the Chief as due, and he will make and note appointments for him, supplying him with an agenda of the day's work each morning.

Secretary.—There remains the Secretary's department. A portion of his work has already been described, and since the greater part is ordinary office routine, common to all commercial concerns, it need not be enlarged on. The Secretary should be paid about the same salary as the Chief Works Clerk. His principal subordinate is the Accountant, who should have had a thorough training as a Chartered Accountant, and be competent to undertake the whole of the financial work, and prepare all books for the Auditors. Under the Accountant will be the Accounts Clerk, whose business it will be to prepare the consumers' accounts from the meter readers' books supplied to him by the Chief Works Clerk; the Cashier, who will have a staff of collectors, receive all money due from the consumers, and pay all trade accounts due for goods supplied to the Undertakers and wages and salaries; and a Pay Clerk, whose duties have already been described.

The Secretary will issue the specifications drawn by the Chief Engineer and receive all tenders for stores and plant, submitting them to the Board of Directors or Committee, and after they have been opened by them, tabulating the prices and passing them on to the Chief Engineer for him to report on to the Board or Committee. He will then draw up the contracts with the selected firms and take all steps necessary to see that they are of proper financial standing.

The Secretary will look after all legal matters that may arise in connection with the work of the department, and if any Parliamentary work is in hand, such as the preparation of bills promoted by the Undertakers or the opposing of bills inimical to their interests, he will take all necessary steps. For this purpose he will communicate with the Solicitors acting for the Undertakers and their Parliamentary agent, and will arrange for the retention of counsel. When the undertaking is owned by a Company, the Secretary will carry out the various duties entailed by the Acts as to registering and allotment of shares, Articles of Association, etc.

Lastly, the Secretary will be responsible for receiving all enquiries as to the supply, and giving information to intending consumers.

CHAPTER XXXIX.

THE CONSUMER.

THE connection of a consumer's installation requires the co-operation of so many departments that it is impossible to give an intelligible account of the routine under the heading of any one; hence it will be best to trace out the whole of the operations from the time the consumer applies for the current until it is turned on. After this the maintenance of this apparatus, the attention to his complaints, the additions to his installation, and its cutting off when necessary will be described.

In what follows it is assumed that the consumer is supplied from a low-pressure network, as will be the case in all large systems.

First of all, the consumer must formally apply for the current, giving certain necessary information about his installation, and entering into an agreement to take the supply for which he has asked.

The particulars necessary are the name and address of the consumer, the nature of his premises, the number of lamps, motors, etc., he intends to have fixed, the name of the contractor fitting up his premises, etc. It is usual to combine with the application a form of undertaking to take the supply for a minimum period. There is no harm in requiring this, but it is of little practical use, since it is obviously impossible to make the consumer use the energy if he does not choose to do so. The forms of application in use in Manchester are reproduced in Forms 60 and 61, pp. 455, 456, a separate one being used for lamps and for motors.

The application having been received by the Secretary, the first thing is to ascertain that there are mains sufficiently near to the premises for the supply to be given. If this be so, the Secretary must satisfy himself that the consumer has a good reputation for financial soundness. If there is any doubt on this point, it is the practice in some towns to demand from the consumer a deposit equal to the estimated amount of his account for one winter's quarter, the Undertakers paying interest on the deposit at a fair rate, say 4 per cent. This is a most excellent system; and in Manchester, where it is at work, the bad debts only amount to about one-twentieth of one per cent. on the total revenue. The Secretary, having settled these

FORM 60.—Application for Energy (Lamps).

No................

(Name of Works here.)

APPLICATION FOR A SUPPLY OF ELECTRICITY.

To (*insert name of Company or Corporation*).

...............hereby give notice to (*insert name of Company or Corporation*) that...........wish to have, and...........hereby agree with (*insert name of Company or Corporation*) to take, for a period of not less than.......................years* from the...............day of.....................190......, a supply of electricity for the premises mentioned below †(1) at the rate of charge of......per unit, as measured by meter, with a minimum charge of.........per quarter,†

or

(2) at the rate...............per quarter for every kilowatt demanded when all lamps or other consuming devices are in use, and......per unit as measured by meter; that is to say, at a fixed charge of.........per quarter for each sixteen-candle power lamp, and ......per unit as measured by the meter; or for motors at the rate of.........per unit as measured by meter, with a minimum charge of...........per quarter, and...........hereby further agree to pay the charges required by the Regulations for the rent of such meter until...........give written notice of...........intention to discontinue using the same, and to allow the authorised servants of the (*insert name of Company or Corporation*) free access thereto at all reasonable times, and to permit them to remove the same for repair or exchange, as and when by them may be considered necessary.

* Insert period of supply. (Minimum one year.)

† Please strike out the rate at which you do not wish to be charged.

Signature of Applicant (in full) ....

Address where supply of Electricity is required................ ....

Township..

Date..

Description of Premises ....

State whether previously a Consumer of Electricity or Gas under (*insert name of Company or Corporation*), and where ....

....

Name and Address of Contractor fitting up Installation........................

....

Particulars of Lamps, &c.

	Incandescent Lamps		Arc Lamps*		Motors			Other Purposes
	No.	Candle Power	No.	Ampères required for each lamp	No.	Volts.	Amp.	
Number of Lamps, etc., fixed, or proposed to be fixed, for which current is required as per application herewith.								

*State whether the Arc Lamps are for fixing inside or outside the premises.

[Size 10½" by 8¼", printed on white paper.]

FORM 61.—Application for Energy (Motors).

No................

(Name of Works here.)

APPLICATION FOR A SUPPLY OF ELECTRICITY FOR MOTORS.

To (*insert name of Company or Corporation*).

............hereby give notice to the (*insert name of Company or Corporation*) that............wish to have, and............hereby agree with (*insert name of Company or Corporation*) to take, for a period of not less than..................years* from the.................day of..........................190......, a supply of electricity for the premises mentioned below at the special rate of charge of.........per unit, as measured by meter, which charge shall apply if and while............use the Motors hereunder specified not less than.........hours (being an average of.........hours per week) during any quarter of a year ending with any of the usual quarter days, provided that if ....shall during any such quarter fail to use the said Motors for less than the aforesaid hours, then the said special rate shall not apply for that quarter, and............will pay for the supply of electricity during that quarter at the rate of.........per unit, as measured by meter ; and............hereby further agree to pay to you the meter charges required by and to observe the Regulations for the time being in force as to the supply of Electric Energy until............give written notice of............intention to determine this agreement, and will allow the authorised servants of (*insert name of Company or Corporation*) free access to the meters in............premises at all reasonable times, and will permit them to remove the same as and when the (*insert name of Company or Corporation*) may consider necessary.

***Insert period of supply. (Minimum one year.)**

Signature of Applicant (In full) ....

Address where supply of Electricity is required....................................

Date ....

Description of Premises..

State whether previously a Consumer of Electricity or Gas under (*insert name of Company or Corporation*), and where } ....

....

Name and address of Contractor fitting up Installation..........................

....

Particulars of Motors.

	Motors		
	No.	Volts	Amperes
Number of Motors fixed, or proposed to be fixed, for which current is required as per application herewith			

[Size 10½" by 8¼", printed on mauve-coloured paper.]

preliminaries, takes a note of the particulars of the application, and passes it on to the Chief Works Clerk. In his office it is dealt with in the consumers' department, and particulars are first entered up in the 'Works Order Book,' reproduced in Form 62, in which a note is made of the number of the application, the date it was received, and the name and address of the consumer. The consumer's Works Order card is then issued, and columns are provided for the date of this issue, and of the dates of connection of the installation and of the return of the card, also for the consumer's number.

FORM 62.—Works Order Book.

APPLICATIONS FOR SUPPLY				WORKS ORDER BOOK				
Application No. and Works Order No.	Date Application Received	Name	Address	District	Date Works Order Issued	Date Installation Connected	Date Works Order Returned	Consumer's Number

[Size of opening 13" by 8".]

The consumer now becomes represented by the 'Consumer's Works Order Card,' and from this point onwards every information is entered on this. The card, which is white, is in two halves, joined by a strong linen back, so that it can be folded in two. The printing on the card is reproduced in form 63, p. 458.

Each consumer is given a number, and each Works Order is also numbered. Thus, if a consumer applies a second time for additional lamps, he retains his original consumer's number, but the new work has a fresh Works Order number, which is identical with the number of his application.

The cards are kept in groups of twenty-five in a series of pigeon holes,

63.—Consumer's Works Order Card.

DISTRICT

CONSUMER'S No.........

(Initials of Works here.)

Works Order No......... Date of Application........................190.....

Method of Charge........................Declared Maximum.........Amperes.

Name..

Address..

Contractor..

Description of Premises..

CONSUMING DEVICES.

LAMPS							MOTORS			OTHER PURPOSES.
INCANDESCENT					ARC					
8-c.p.	16-c.p.	32-c.p.	50-c.p.	Various	No.	Current	No.	Volts	Amperes	

Contractor to divide into...........Circuits.

Remarks..

....

....

TO MAINS DEPT.

FUSES.			METERS.		
NUMBER	TYPE	SIZE OF FUSES	NUMBER	SIZE	TYPE

Service......Cables..............S.W.G. Armd. Connected to..............

" ...... " .... " " " ....

To be run in..

How attached to Distributing Main..

I DIRECT THE ABOVE WORK TO BE PROCEEDED WITH AT ONCE.

....
Chief Engineer.

Date...................................190...

(Initials of Works here.)

Insulation Resistance.................Megohms. Weather........................

How Measured.................Tested.................190... By........................

Consumer's Leads joined to Fuse } ....190... By........................

Polarity of Mains........................ Tested by........................

Light turned on.................190... By........................

Witnessed by..
Consumer.

Remarks..

....

CONSUMING DEVICES ACTUALLY INSTALLED.

DATE	LAMPS							MOTORS			OTHER PURPOSES
	INCANDESCENT					ARC					
	8-c.p.	16-c.p.	32-c.p.	50-c.p.	Various	No.	Current	No.	Volts	Amperes	
......	......	......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......	......	......	......

FUSES fixed.................190... Size.................. By........................

Type........................ Where situated..

METERS fixed..............190...... By..

Corporation No.	Maker's No.	MAKER.	READING	SIZE	Readings X By	No. of Amperes controlled

Service run...........................190... By........................

Joints made...........................190... By........................

Mains attached to Fuse....................190... By........................

Box No............... Service Cables..............................S. W. G.

Built..........................190... By........................

....
Foreman of Mains Department. Electric Inspector.

Date returned..............................190.....

[... printed one side only, and attached at back with linen hinge. Size of each card, about 8" by 5".]

numbered according to the Works Order numbers. The cupboard is thus, in effect, a book, of which the Works Order cards are the leaves. The index to this book is a card index, consisting of a series of cards contained in a set of drawers, and arranged alphabetically. The cards are all of the

FORM 64.—Index Card.

(Front of Card)

(Name of Works here.)

Consumer's No....................

Name..

Address...

District..

Works Order Nos...

....

Folio in Connections Book..

....

Remarks..

....

....

(Back of Card)

PARTICULARS OF METERS.

Corp. No.	Maker's No.	Maker's Name	Size	Readings X by	Date fixed	Reading when fixed	Date removed	Reading when removed

[Size, 3″ by 5″.]

same size, about 3 inches by 5 inches, and are of thin cardboard; each has a hole punched in the edge, resembling in form a keyhole for a key with a disproportionately large barrel. The cards just fit into the drawer, and are placed on edge, the holes being on the bottom. The holes punched in them

slip over a flat bar placed in the lower part of the drawer when it is in an upright position, but on giving it a quarter turn, the bar which has entered the wide part locks the cards, which cannot then be withdrawn. By this means the cards are normally held in position, but any one can be instantly withdrawn and replaced by turning the bar round. One great advantage of this index is that any number of entries under one letter can be made, and all new entries can be made strictly in alphabetical order, while obsolete matter can be eliminated, and in no case are the other cards disturbed. The index cards can contain any desired information. A specimen card is shown in Form 64, p. 459.

The particulars on the application form are entered up on the Works

FORM 65.—Enamelled Iron Label.

(Initials of Works here—large.)

Position of electric meter and fuse

[Size 2½" by 4⅓". White letters on dark red.]

Order card, the two numbers—viz., that of the Order and consumer's number are filled in in the spaces provided, and the name, address, and Works Order number repeated on the outside of the card when folded, the name of the district in which the premises are situated being added. The original application is then returned to the Secretary, and is filed away by him.

If the application should include motors that will be supplied at a pressure exceeding 250 volts, notice is sent to the consumer to the effect that he must make application jointly with the Undertakers for a supply at this pressure, and the form of application, reproduced in Form 14, p. 381, is enclosed for his signature.

The Works Order card is then sent to the Mains Engineer, who passes it on to the foreman of the district in which the premises are. The district foreman visits the premises, selects the position for the meter, and affixes an enamelled iron label, reproduced in Form 65, to mark the spot. He makes enquiries, and from these, combined with his own observation, judges of the likelihood of extensions beyond the original application, whether from the particular consumer or other occupants of the building. When the service has been settled, the card is marked on the back in the corner with a capital L to show this has been done.

The district foreman then attends before the Mains Engineer, and gives him all the information he has gathered. The Chief Draughtsman attends

FORM 66.—Order to Lay Service.

[Insert address here.]

....190

[Insert here—name of Works
or Corporation and the
Chief Engineer's name, &c.]

DEAR SIR,

With reference to your application for a supply of electrical energy, I have to remind you that it is incumbent on the consumer, in the case where a garden intervenes between his premises and the roadway, to lay at his own cost so much of his service line as is in his own grounds. This service can either be laid by the Contractor for the internal wiring of your premises, or (*name of Works or Corporation*) will carry out the work at cost price, if you so desire. The latter is, I may say, the usual course. If you wish this done in your case, will you kindly detach the annexed form, and return it to me duly filled in and signed.

Yours truly,

....

Chief Engineer.

[Name of Works here.]

APPLICATION TO PROVIDE AND FIX PORTION OF CONSUMER'S WIRES FOR ELECTRIC LIGHTING.

To (name of Works, Committee, or
Corporation here)

I request you to lay the necessary service conductors to my premises from the termination of your service main to the point of connection with the internal wiring and I hereby agree to pay to you the cost of providing and laying the said service conductors together with the cost of the necessary excavating filling in and making good of the ground. I further undertake to make no claims upon (*name of Works or Corporation*) for and to keep them indemnified against any damage whatsoever that may be done to walls garden paths trees flowers shrubs or other property whether belonging to me or any other person or persons.

Signature of Consumer..

Date...

Address..

....

[Ordinary business notepaper, printed on 1st and 4th pages.]

at the same time with full particulars of the mains, balancing, etc. The Mains Engineer then makes out the actual Works Order, giving particulars of the number of circuits required, the fuses, the meters, the service lines, and the poles from which they are to be fed. If there be any special difficulty, he consults the Chief Engineer, by whom the card is signed. If a garden or yard intervenes between the consumer's premises and the street, it is usual to charge for the portion of the service main laid on his property. If the work be done by the Undertakers, as is certainly desirable from all

FORM 67.—Label Notice.

(Name of Works here.) (Insert Address here.) ....*190*... *M*.......... .... *Dear Sir,* *Re Installation at M*.................................. ... . *Please note that a label has to-day been fixed marking the position of the main fuse and meter at this address. The pressure of supply will be ....volts, and it will be necessary for the lamps to be divided into.........approximately equally loaded circuits, the service being a.........wire one.* *When your work is* <u>*ENTIRELY*</u> *finished and the Installation ready for turning on, please fill in the accompanying form and return same to me.* *Yours truly,* *Chief Engineer.* **N.B.—Unless the attached form is returned there may be great delay in connection.**	(perforated here.)	(Name of Works here.) *From M*..................................... ....*190*... *To the Chief Engineer,* *Electric Light Station,* (Insert Address here.) *Dear Sir,* *Re Installation at*.. .... *Please note that we have* <u>*ENTIRELY COMPLETED*</u> *our work at this Installation, and it is now ready for final inspection.* *Yours truly,* *Contractor.*

[Ordinary business notepaper; printed on 2nd and 3rd pages.]

points of view, it is prudent to have an indemnity from the consumer in the event of damage being done; the form devised by the Author is shown in form 66, p. 461.

As soon as the Works Order has been issued a notice is sent to the consumer's contractor informing him that the label showing the position of the meter has been fixed, thus giving him the point he has to wire to, and, at the same time, particulars as to the pressure of supply and number of circuits required are given. The form is reproduced in Form 67. The

FORM 68.—Consumers' Book.

NAME .... **ADDRESS** .... **CONSUMERS' No.** ....

CONTRACTOR .... **DESCRIPTION OF PREMISES** .... **DISTRICT No.** ....

CONSUMING DEVICES

(17181)

DATE	Application No.	LAMPS						MOTORS			Other Purposes	Rate of Charge	Insulation Resistance			Meter		Amperes controlled Polarity.				
		Incandescent				Arcs																
		8 CP	16 CP	32 CP	VARIOUS	NO.	AMPS.	NO	VOLTS	AMPS.			DATE	CIRCUIT	MEGS.	ISSUE NO.	SIZE	+	⊕	○	⊖	—
CONNE	CTED W.O.	NO.																				

FUSES fixed...190 . Size...

„ fixed...190 . Size...

Type ....

Situated ....

SERVICE ....

Connected to

Cables......×...S. W. G.......

„ ......×...S. W. G.......

„ ......×...S. W. G.......

„ ......×...S. W. G.......

„ ......×...S. W. G.......

Joints made by..............

....

How attached..............

....

Maximum Recorders.

DATE	NO.	SIZE	METER NO
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....

REMARKS :—

[Size of page, 8½" by 13", or two forms can appear on a page 17" by 13".]

date on which this notice is sent is entered within the L written on the Works Order card by the district foreman, in order to indicate that the notice has been sent.

The Works Order card is returned, after being signed by the Chief Engineer, to the district foreman, who then has the service laid, and the uses and meter board fixed. He then passes the card on to the Installation Inspector, after having filled in the blanks for the names of the various men engaged, and the dates on which the various portions of the work were done.

The Installation Inspector passes on the card to one of the assistant inspectors, who examines the installation from time to time while it is being wired, and sees the contractor, answering his enquiries, and taking care that the regulations are adhered to.

When the notice of completion is returned by the contractor, it is passed on to the Mains Engineer, who has the meter fixed and the consumer's cables left ready to put the one into the meter, the other into the main fuse. The completion notice is then handed to the Installation Inspector, and the installation is finally inspected, its insulation resistance tested, and the lamps counted. If all is in order, the Inspector puts the consumer's wires into the meter, tests that it is connected properly, tests the polarity of the mains, comparing it with that shown on the Works Order, and then turns on the supply, having inserted the main fuses, and sealed the fuse box and meter terminals. Symbols are placed on the outside of the fuse boxes to show their polarity. If motors or arc lamps be fixed, the current taken by them is measured.

If the insulation resistance is not up to the standard, but in the judgment of the Inspector the work is well done and the resistance is likely to rise, the installation is turned on conditionally for a time, if the consumer signs the form already reproduced in Form 21, p. 406, the consumer being advised as to the matter on the first portion of this form.

All the particulars mentioned are entered up in the blanks provided on the card, and it is then returned to the Chief Engineer, who examines and initials it, when it is returned through the Chief Works Clerk to the consumer's department. Here all the particulars are entered up in the 'Consumer's Book,' reproduced in Form 68, p. 463. This book is of use, inasmuch as it summarises all the Works Order cards relating to a given consumer, corresponding in large measure to the permanent maps in the Mains Department, which summarise the various tracings, and enables the present state of the installation to be at once seen, while particulars of periodical tests of the insulation resistance, maximum demand, etc., are entered in the book from time to time.

A list of all consumers is kept by the Works Consumers Department in which the consumers' names are arranged under the various streets, which

are kept in alphabetical order; the equivalent in ampères of all their consuming devices is placed opposite their names, being written in columns representing the various conductors forming the network. This list is forwarded each day to the Chief Draughtsman, so that particulars of the

FORM 69.—Disconnection Works Order Card.

District No............

Consumer's No............

(Name of Works here)

Works Order No..................... Date..................1......

Name...

Address..

Why Disconnected...

TO MAINS DEPT.—*Remove Meter*

Date	Number	Size	Reading

Removed by

....

Disconnect Service and remove Fuse and Board by......................1......

SERVICE				FUSES	
Size of Leads	Length	Size of Pipe	Length	Number	Size

Mains made good by...

Date of Disconnection ....1......

I DIRECT THE ABOVE WORK TO BE PROCEEDED WITH AT ONCE.

....

Chief Engineer.

Date......................1......

[Size 8″ by 5″; printed on thin, pink cardboard.]

balancing may be recorded in the Drawing Office books and on the balancing sheets.

The Installation Inspector makes a daily return to the Chief Engineer of all connections and disconnections on the forms already given in Forms 23, 24, on p. 408, and the head of the standardising department reports

the meters fixed and removed on the forms shown in Forms 33, 34, on pp. 419, 420. These forms, after being initialled by the Chief Engineer, are passed on to the Secretary together with the Works Order cards, and, the information required for the books of his department having been abstracted, they are returned to the Chief Engineer and filed away.

It will be observed that, from the moment the application is received to the time the supply is turned on, and all particulars of the transaction are entered up in the books of the various departments, every new consumer, or the additional requirements of an old one, is represented by a concrete card which has to go through a definite routine, and which cannot well be forgotten or overlooked. The importance of this, in practice, in preventing confusion and mistakes is very great.

So much for the connection of the consumer's installations. When it becomes necessary to disconnect one, a Works Order to do so is issued. This is of such a size as to fit into the construction Works Order card, and is pink to distinguish it. This card is reproduced in Form 69, p. 465.

The installation is inspected from time to time by the 'fuse cleaners.' These consist of an intelligent youth who can make a simple test and a skilled labourer; these between them clean all the Undertakers' apparatus fixed on the consumers' premises, renew the fuses (if necessary) and test whether the insulation is good, try whether the meter will start properly, go over all the contacts to see that they are tight, see that the meters and fuses are sealed properly, test the insulation resistance of the consumer's installation, and count his lamps to see that no unauthorised alterations have been made. The results of all these tests are recorded on a card which is reproduced in Form 26, p. 410.

If the lamps have been altered in number, the alteration is reported on the daily connection or disconnection sheets as the case may be.

If the insulation resistance be found to be below the standard fixed by the Board of Trade, the installation is cut off within twenty-four hours, the notice, Form 22, p. 407, having been served on the consumer.

If a consumer make a complaint as to the supply, the Chief Engineer issues the notice reproduced in Form 27, p. 411, to the Installation Inspector, who fully examines into the matter and reports to the Chief Engineer. A register is kept of all complaints made and of the Inspector's reports thereon (see p. 412).

If a consumer dispute his account, a note is issued to the Installation Inspector informing him of the nature of the objection, accompanied by particulars of the account; this form (see p. 413) is filled in and returned by the Inspector.

In the event of any alteration being made by a consumer in his lamps, the maximum demand is ascertained, and reported on the form shown in Form 25, p. 409.

CHAPTER XL.

THE ROUTINE OF MAIN LAYING.

As in the case of connecting a consumer's installation to the mains, the laying of a main trenches on the work of several departments, and in order that the whole process may be intelligible, it will be convenient to describe the routine followed in a separate chapter.

We will assume that it is determined to lay mains in certain streets. If the extension be an important one, the Chief Engineer will first walk over the ground in company with the Mains Engineer, or, if of less importance, the latter will examine the district and report to the Chief. This preliminary inspection should never be omitted, as without it the difficulty of forming a correct estimate of the needs of the locality is greatly increased.

The preliminary inspection made, the first thing is for the Drawing Office staff to obtain as much information as possible as to the streets in question. The number, size, and location of gas, water, and other pipes are ascertained, and examination made for the presence of obstacles, such as main gas or water valves, sewer manholes and ventilating shafts or cellars; the presence of bakers' ovens, especially, should be duly noted, as the heat from them is very likely to cause damage to cables. Enquiry must be made as to whether improvements are contemplated, and whether there is, therefore, any likelihood of the street being widened or the buildings set back; if such is found to be the case, the mains must either be laid within the new line of kerb, or be made strong enough to bear the heavy traffic when they are subsequently left in the roadway.

Having obtained as many of these particulars as practicable, a tracing is made of the whole line of each street on a single continuous tracing, or on several if the route be a long one or the street be much curved. The ten feet to the mile Ordnance maps are used for this purpose, the buildings along the street in which the main is to be laid being shown, but only so much of the side streets as is necessary to clearly indicate the points where they branch off. The pipes are laid down on this tracing, together with the

FORM 70.—Mains Works Order Card—Construction.

[A white folding card strengthened at back with linen joint—size, folded, about 5" by 4".]

1st page.

No. A....................

CONSTRUCTION.

MAINS.

Date returned,.....................*190*......

2nd page.

Works Order No. A....................... *Date*,......................*190*......

TO MAINS DEPT.—

Please...

3rd page.

....
Chief Engineer.

Work begun,.......................*190*...... *Completed*,.......................*190*......

....
Mains Engineer.

COST.

	£	s.	d.
Labour			
Material			
Repairing services			
Re-flagging, etc. ...			
Carting..............			
Tipping			
TOTAL COST			

FORM 71.—Mains Works Order Card—Maintenance.

[A green folding card strengthened at back with linen joint—size, folded, about 5″ by 4″.]

1st page.

No. A......................

MAINTENANCE.

MAINS.

....

Date returned,..............................*190*......

2nd page.

Works Order No. A........................ ***Date,***......................***190***......

TO MAINS DEPT.:—

Please..

3rd page.

....

Chief Engineer.

Work begun,........................***190***...... ***Completed,***........................***190***......

....

Mains Engineer.

		£	s.	d.
COST.	Labour			
	Material			
	Re-flagging, etc. ...			
	TOTAL COST			

new building line if alterations be contemplated, and any obstacles resp ing which information has been obtained.

A print, preferably a white one with black lines, is then taken of tracing and forwarded to the Chief Engineer. He then determines the of main that is to be laid and the particular kind that is to be used, culvert, pipe, or solid system, and full particulars of every length written in by the Chief Draughtsman on the print, and the position junction boxes marked.

A full description of the work to be done is then written out o Works Order card, to which a distinguishing number is assigned. T card is shown in Form 70, and is strongly made, folding in halves. order is written on the inside and signed by the Chief Engineer; blanks provided at the lower portion in which the cost of the various items can entered up when the job is complete and a record kept of the total o The dates at which the work is begun and ended are also filled in, so t the time taken can be seen. This portion of the card will be referred later on. On the outside of the card is written the number of the o and the name of the street. It may here be mentioned that w maintenance or repair work is to be done, a similar card is used (Form 7 but it is coloured green in order to distinguish it.

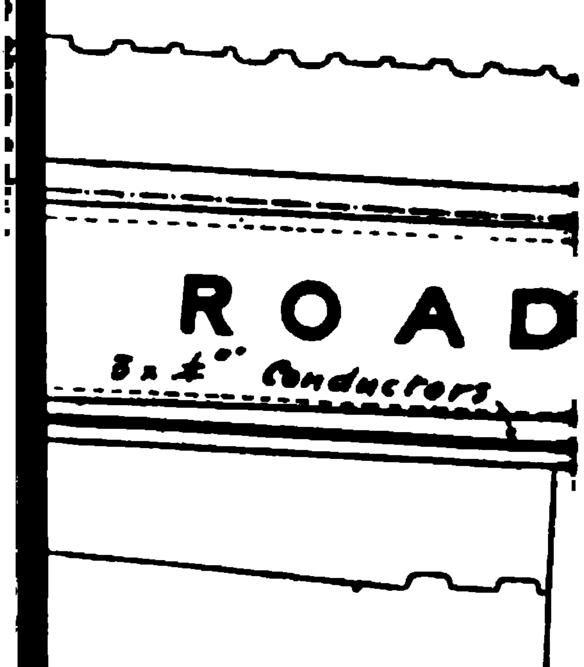
A sample plan of a street is shown in fig. 136 opposite, and the follow is a typical Works Order showing the kind of instructions issued on card shown in Form 70:—

Please construct manhole, and fix therein a 3-way Pillar distributor at the corn of the S.E. side of Plymouth Grove, and the corner of the S.W. side of Stockp Road. From this pillar construct 3-way Crompton Culvert, and fix therein th ½-square inch conductors on the S.W. side of Stockport Road, to the corner of t N.W. side of Richmond Grove. Street crossings to be made with three ½-square in vulcanised bitumen cables on Callender's solid system. From the termination these mains lay three ½-square inch vulcanised bitumen cables on Callender's so system, to the corner of the S.E. side of Daisy Bank Road.

The Works Order having been made out, a copy is sent to the Chief Draughtsman, so that he may have full particulars for preparing the print, and when this is ready it is sent together with the actual Works Order to the Mains Engineer.

The first thing the Mains Engineer has to do is to find whether the requisite materials for carrying out the work are in stock, and to requisition through the book provided for the purpose (see p. 432) such as are wanting. He also sees that he has all the appliances and tools necessary.

Everything being ready, he decides upon the number of gangs required, this being chiefly determined by the rapidity with which the work has to be done. A kind of depot is formed in some quiet spot in a side street, and a cabin set up in which the foreman can keep his papers and the tools


ROAD
3 x 4" Conductors

be placed at night. If possible, a temporary shelter for the men is arranged, so that they can have their meals with some degree of comfort.

Unless absolutely necessary, work should not be done at night, as night gangs are rarely satisfactory. Not only is there much greater likelihood of the men idling, but there is great danger of the work not being so well done. In certain cases, however, it is unavoidable, as, for instance, in exceptionally busy thoroughfares, or at important road crossings, or when a piece of work has to be pushed forward at a very rapid rate. Under these circumstances, especial care should be taken to choose steady and sober men, and as good a light as possible should be furnished, so that they may see what they are doing. Electric light can rarely be arranged for, as the work in hand is usually an extension, and therefore away from the mains. Wells' lamps give a very fair light, but they are not altogether desirable in a public thoroughfare. Large paraffin lamps in fair numbers are fairly satisfactory.

The utmost care must be exercised to thoroughly and effectually fence round the trenches and the heaps of material removed from them. The fencing should be put up in advance of the men, so that they do not begin to disturb the surface of the footpath until the space has been enclosed.

The most usual fencing is spun yarn or, what is much better, a light chain, supported on steel pins driven into the ground. Occasionally trestles and poles are used, but these take more room and are costly to move about.

It is, of course, necessary to provide gangways at intervals, so that the trench may be crossed in safety. For this purpose, 'path-boards,' consisting of planks nailed to battens to form a platform about four feet six inches wide, may be used, or, as is far better, strong bridges, about two feet six inches wide, having a strong wooden balustrade, carried by uprights secured by angle-irons.

At night, plenty of lamps should be used to thoroughly mark out the disturbed area, and a separate watchman must be employed for each job.

It is impossible to take too much care in guarding the excavations, as even, when every precaution has been taken, accidents will happen through persons tripping or slipping, and occasionally actual injury may result, though the claims for compensation that are sent in on the slightest pretext are, in the majority of cases, bogus ones. In order to guard against these claims, the strictest injunctions should be given to foremen to at once report even the most trivial mishap, whether complaint be made to them or not, so that evidence may be available as to the occurrence. Immediately on receipt of a claim, a doctor should be sent to see the claimant and report on his alleged injuries. If the case be a genuine one, it is wise to settle it immediately, even though there be a doubt as to the liability, as a few pounds will probably dispose of the matter, whereas, if put off and taken

into court, the costs may be very heavy, and a jury nearly always finds against a wealthy company, and especially against a corporation. If an attempt at extortion be made, however, it should be resisted at all hazards, if only to deter others.

It is inevitable, during the laying of a main, that damage should be done from time to time to gas, water, or other pipes; when such mishaps occur, notice should instantly be sent to the authorities whose property is affected. Suitable forms of notice for the purpose are shown in Forms 72 and 73.

On opening the ground, it is often found that leaks exist without any damage having been done to the pipes during the operations. In the case of gas, any leakage, from whatever cause arising, is required by the Board of Trade to be notified to the Gas Authority, and it is prudent to obtain a signed acknowledgment from them that the notification has been duly served.

No such notice is necessary in the case of leaky water pipes, but it is a great boon to the Water Company, or to the department, to be advised of any cases met with; and to do so, although of no direct benefit to the electrical company, promotes a friendly feeling which cannot be too sedulously cultivated between those who share the very limited space under the pavement.

A form devised by the Author to deal with these cases is shown in Form 74 for water, and in Form 75 for gas.

The Undertakers have the right to require the removal of pipes that obstruct the laying of their mains, provided that they bear the cost of the removal. Apart from the expense, the right should not be exercised to a greater extent than is absolutely necessary, as it is liable to cause friction.

Before beginning work in a given street, it is usual to give forty-eight hours' notice to the Post Office and Gas and Water Authorities. Some engineers object to this course; but, on the whole, it is probably best for all parties, as it enables the owners of pipes to watch the proceedings of the Undertakers, in which case subsequent disputes are much less likely to arise. In cases of special urgency there is usually little difficulty in getting the formal notice dispensed with, provided that the Post Office or other officials are advised of the work.

Returning to the actual laying of the main, the footpath is always chosen in preference to the roadway, on account of the traffic being so much lighter. As the excavations proceed, the job is visited by a surveyor from the Drawing Office, and if a culvert be under construction or a pipe is being laid, he sets out the gradients to give the necessary fall.

The main itself is then completed, the series of operations, of course, varying with the type. Into these details it is unnecessary to enter here. In all cases, the requisite stores are ordered on to the job from the store-

FORM 72.—Notice of Damage to Gas Pipe.

(Name of Works here.)

No.......................

URGENT.

DAMAGE TO GAS PIPE.

To the Superintendent,
Corporation (or other) Gas Works.

Please note that a gas pipe has been damaged by workmen of this Department at...
....
....

Your immediate attention will oblige.

....
Mains Foreman.

AN OFFICIAL ORDER WILL FOLLOW.

....Perforated..

(Name of Works here.)

No...................

Notice of Damage to gas pipe at...
....received from
to-day at........................a.m.

....
Clerk.

Date..*190*

Please sign and return this portion to bearer.

Official Order Sent...190 *No.*...............

[Size 8″ by 5″; printed in red type on white paper.]

FORM 73.—Notice of Damage to Water Pipe.

(Name of Works here.)

No...................

URGENT.

Damage to Water Pipe.

To the Corporation (or other) Water Works.

Please note that a water pipe has been damaged by workmen of this Department at...
....
....

Your immediate attention will oblige.

....
Mains Foreman.

AN OFFICIAL ORDER WILL FOLLOW.

....Perforated..

(Name of Works here.)

No...................

Notice of Damage to water pipe at...
....received from
to-day at...a.m.

....
Chief Clerk, Mains Department.

Date..*190*

Please sign and return this portion to bearer.

Official Order Sent...*190* *No.*...............

[Size 8″ by 5″; printed in red type on white paper.]

ORM 74.—Notice of Water Leakage.

(Name of Works here.)

No...................

Leakage of Water.—URGENT.

To the

Corporation (or other) Water Works.

Please note that a leakage of Water has been observed by this Department at..

....

....

Your immediate attention will oblige,

....

Mains Foreman.

....Perforated..

(Name of Works here.)

No...................

Notice of leakage of Water at..

....

received from to-day at.................................... .m.

....

Chief Clerk, Mains Dept.

Date......................................190

Please sign and return this portion to bearer.

[Size 8" by 5".]

FORM 75.—Notice of Gas Leakage.

(Name of Works here.)

No...................

Leakage of Gas.—URGENT.

To the Superintendent,

Corporation (or other) Gas Works.

Please note that a leakage of Gas has been observed by this Department at..

....

....

Your immediate attention will oblige,

....

Mains Foreman.

....Perforated..

(Name of Works here.)

No...................

Notice of leakage of Gas at..

....

received from to-day at.................................... .m

....

Clerk.

Date......................................190

Please sign and return this portion to bearer.

[Size 8" by 5".]

keeper by means of orders signed by the foreman, as described in Chapter XXXVIII. The foreman also looks after the booking on of the men, receiving, checking, and initialling their time-sheets. The utmost care is necessary in attending to the accuracy of the record of both the materials and time, otherwise it will be impossible to correctly gauge the cost of the work. In extensive operations, it often pays to employ a kind of travelling clerk to go round to the various gangs and assist the foreman in this work and check the accuracy of his figures. The great danger of error lies in the chance of carelessness in the examination of the time-sheets, and in the booking of the material to the proper Works Orders. With a view to keeping this matter in order, one gang should never be allowed to borrow stores from another, and goods should be delivered in distinct consignments to each job. This remark does not, of course, apply to the transfer of stores from one Works Order to another, whether carried out by the same gang or some other, an operation described in Chapter XXXVIII.

A similar course should be pursued as to the tools. Each gang should have its own tools, for which its foreman is held responsible, and he must be strictly forbidden to lend to, or borrow from, other gangs. When a job is finished, the whole of the tools and plant should be returned to the stores, and the quantities checked and condition examined previous to reissue.

It is very desirable when laying cable to constantly make a rough test of its insulation resistance, as by this means a fault will be found at once. When a length is completed, the pressure test, described in Chapter XXIII., should be applied, and after that the insulation test. The district foreman and his assistants will prepare the ends of the cables for this test, and if the various lengths of conductor prove satisfactory, will make the joints between them and connect them up to form the complete main. After this has been done, it is again tested for insulation resistance, and also with high pressure if a machine of sufficient capacity be available.

Before the ground is filled in, surveyors from the Drawing Office will take the necessary measurements to enable the course of the main to be accurately laid down on the plans; the arrangements for this have already been fully described in Chapter XXIV.

When the ground is filled in again, the flagging or paving is roughly replaced, and an order to make it good permanently is sent to the Highways Authority. This is the most usual course, though sometimes the Undertakers make it good themselves. It is more satisfactory to let the Highways Authority do the work, as, for a fixed payment per yard, they take all responsibility for the maintenance if the ground should sink after the paving has been made good.

The carters employed for carting away the spoil will probably be hired from a contractor. These men require most careful watching, and each should be provided with a book shown in Form 76, in which he has to enter

FORM 76.—Carter's Day Book.

CARTER'S DAY BOOK.

Date,........................*190*

Carter ....

Name of Driver ....

Start.........................*Signed*..................................

MATERIAL	FROM	TO	FOREMAN'S SIGNATURE
Work ended	....		
	(Signed)	....	....

[Size 8″ by 5″.]

FORM 77.—Tip Note.

(Name of Works here.)

No.............

.............................*190*...

M..

Please allow bearer to tip

LOAD RUBBISH

W.O............

....

(Perforated.)

(Name of Works here.)

No.............

.............................*190*...

M..

Please allow bearer to tip

LOAD RUBBISH

W.O............

....

[Size 4″ by 8″.]

the nature of the load, the place from which it is carted and its destination, and he is required to get the mains foreman's signature for each load. In addition to this, the foreman has to certify as to the time of starting and concluding each day's work. In the event of any journey occupying an excessive time the foreman makes a note calling attention to the fact.

No carter is allowed to work overtime unless authorised in writing to do so.

For each load of material tipped, the carter must give a 'tip-note,' shown in Form 77, which the owner of the tip has to send in with his account for the reception of the material.

The cable or bare copper necessarily forms by far the most valuable portion of the stores issued, and the loss of a few yards in the case of a heavy main may represent a considerable sum of money. For this reason a somewhat elaborate system of checking the quantities used is desirable. That arranged by the Author is as follows :—The order for cable required for mains is made out by the mains foreman on the form reproduced in Form 78, in the space provided, and specifies the length, size, kind of cable, and maker's name, giving also the number of the Works Order for which it is required. The foreman keeps a note of his order on the counterfoil; he then tears out the order and sends it to the Storekeeper.

The Storekeeper, on issuing the cable, fills in and detaches the bottom half of the order and forwards it to the Chief Draughtsman, thus notifying him that cable has been issued for a certain Works Order, without, however, giving any clue as to the quantity.

The Chief Draughtsman measures up the cable actually used on the job and fills in, on the back of the slip he received from the Storekeeper, the particulars he has obtained from independent measurement, and forwards the slip to the Chief Engineer; this slip is then compared with the original order, and any discrepancy at once investigated.

A precisely similar routine is followed in the case of copper strip, the form for which is reproduced in Form 79.

For service cables a very similar method of checking is adopted, but in this case the Storekeeper advises the Chief Draughtsman of the actual lengths of the cables issued, and the latter merely certifies that they are substantially correct. This is sufficient, as the value of the material involved is much less than in the case of large mains, and the lengths cannot be measured quite so accurately owing to the cables going round bends, through walls, and into buildings. The form used is reproduced in Form 80.

It will be seen that the check on the material is absolute, and that it is very difficult for any to go astray.

The cost of the main is determined with the greatest care; all the material issued under a particular Works Order is entered in a book

FORM 78.—Cable Order Form.

Front of Form.

(Initials of Works here.)

MAINS.

No..........

Date.............1......

W.O.......................

CABLE.

LENGTH	SIZE	PARTICULARS
YARDS.		

Manufacturer............

Issued to..................

....

Perforated

(Initials of Works here.)

ORDER FOR CABLES. **MAINS.**

No....... *Date*...........1......

To STOREKEEPER,

Please give bearer......................................

the following Cable for W.O. ....

LENGTH	SIZE	PARTICULARS	MANUFACTURER
............*yards.*	....	....	....
............*yards.*	....	....	....
............*yards.*	....	....	....
............*yards.*	....	....	....
............*yards.*	....	....	....

.................................*Foreman.*

.... Perforated ....

(Initials of Works here.)

CABLE FOR MAINS. *Date*.........1...

No.......

To DRAUGHTSMAN,

Please note that I have to-day issued Cable to be laid under W.O. ....

....

Storekeeper.

Back of Form.

.... Perforated ....

Perforated

(Initials of Works here.)

CABLE FOR MAINS. *Date*.......... 1...

To CHIEF ENGINEER,

Please note that I have to-day measured the Cable referred to on back hereof and find it to be—

LENGTH	SIZE	PARTICULARS	MANUFACTURER
..............*yards.*	....	....	....
..............*yards.*	....	....	....
..............*yards.*	....	....	....
..............*yards.*	....	....	....
..............*yards.*	....	....	....

.........................*Draughtsman.*

[Size 5½" by 10".]

FORM 79.—Strip Order Form.

Front of Form.

(Initials of Works here.)

MAINS.

No........

Date...........................

W.O...................

COPPER STRIP.

Coils	Length Feet	Size	Weight			

Manufacturer................

Issued to.......................

....

For section....................

....

Perforated

(Initials of Works here).

ORDER FOR COPPER STRIP. **MAINS.**

No........ *Date*............1......

To STOREKEEPER,

Please give bearer....................................

the following Copper Strip for W.O............................

Coils	Length in Feet	Particulars	Weight				Manufacturer

....................................*Foreman.*

.... Perforated ....

(Initials of Works here.)

COPPER STRIP FOR MAINS. *Date*.........1...

No........

To DRAUGHTSMAN,

Please note that I have to-day issued Copper Strip to be laid under W.O. ....

....

Storekeeper.

Back of Form.

....Perforated..

(Initials of Works here)

COPPER STRIP FOR MAINS. *Date*...........1......

To CHIEF ENGINEER,

Please note that I have to-day measured the Copper Strip referred to on back hereof and find it to be—

Coils	Length in Feet	Particulars	Weight				Manufacturer

....*Draughtsman.*

Perforated

[Size 5½" by 10".]

FORM 80.—Service Cable Order Form.

Front of Form.

(Initials of Works here.)

SERVICES.

No.......

Date.................1......

W.O.......................

CABLE.

LENGTH	SIZE	PARTICULARS
YARDS		

Manufacturer...............

Issued to.....................

....

Perforated.

(Initials of Works here.)

ORDER FOR CABLE. SERVICES.

No....... *To STOREKEEPER,* *Date...........1...*

Please give bearer.............................the following Cable for W.O............ ....

LENGTH	SIZE	PARTICULARS	MANUFACTURER
.............*yards.*	....	....	....
.............*yards.*	....	....	....
.............*yards.*	....	....	....
.............*yards.*	....	....	....
.............*yards.*	....	....	....

........................*Mains Engineer.*

..................................Perforated..................................

(Initials of Works here.)

CABLE FOR SERVICES. *Date.........1...*

No...... *To DRAUGHTSMAN,*

Please note that I have to-day issued the following Cable for W.O.........................

SIZE	LENGTH	WEIGHT	PARTICULARS	MANUFACTURER
....	.............*yards.*	....	....	....
....	.............*yards.*	....	....	....
....	.............*yards.*	....	....	....
....	.............*yards.*	....	....	....
....	.............*yards.*	....	....	....

........................*Storekeeper.*

Back of Form.

..................................Perforated..................................

(Initials of Works here.)

CABLE FOR SERVICES.

Date...........1......

To CHIEF ENGINEER,

Please note that I have checked the particulars of Cable referred to on back hereof, and find them to be substantially correct.

............................*Chief Draughtsman.*

Perforated.

[Size 5½" by 10".]

devoted to the purpose, a separate folio being assigned to each number, and when the main is completed, the total cost analysed under the various headings shown on the forms reproduced on p. 468 is entered on the Works Order card.

It need not be said that the closest observation should be exercised over the whole staff when at work; no matter how excellent the workmen may be, or how conscientious the foreman, or how strict the walking foreman, the Mains Engineer himself should frequently visit each job, timing his arrival so as not to be expected.

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